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EXPANSION OF INVESTIGATION OF PASSENGER CAR REFUELING LOSSES THIRD-YEAR PROGRAM

Malcolm Smith, et al

Scott Environmental Technology, Incorporated

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EXPANSION OF INVESTIGATION OF PASSENGER CAR REFUELING LOSSES

THIRD-YEAR PROGRAM

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Coordinating Research Council, Inc.
Thirty Rockefeller Plaza
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and

Environmental Protection Agency
Office of Air and Water Programs
2565 Plymouth Road
Ann Arbor, Michigan 48105

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Program Conducted by:

Scott Environmental Technology, Inc.
2600 Cajon Boulevard
San Bernardino, California 92411

Report Written by:

Malcolm Smith
Olson Research Laboratories
and
William F. Biller
Consultant

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Summary

This report covers the third year of the program on passenger car refueling losses undertaken for the Coordinating Research Council and the Environmental Protection Agency by Scott Environmental Technology, Inc.* The objective of the third year was the development of a mathematical model for estimating the total hydrocarbon losses from refueling operations for an air quality control region over a specified period of time. In order that the model could be used readily by community planners and others it was based on relatively easily obtained variables such as average Reid vapor pressure of the gasolines used in the region and average underground fuel and ambient temperatures.

The model requires estimates of losses due to spillage and those which are displaced from the fuel tank as vapor and entrained fuel droplets during refueling. The second year program determined through field studies that spill losses average 0.30 gms/gal of dispensed fuel. A mathematical expression for estimating the displaced hydrocarbon losses was also developed in the second year by the application of stepwise multiple regression analysis to laboratory measurements of losses under controlled conditions. This expression was considered inadequate for use in developing the regional model because it was based on a small, incomplete data base and too narrow a range of fuel Reid vapor pressures. As a result, the laboratory study was redone in the third year to provide a new, more comprehensive data base needed for a more reliable expression. Multiple regression analysis yielded the following expression:

$$L'_D = \exp (a + b\, P_V T_D + c\, T_T + d\, P_V + e\, T_D T_T)$$

$a = -9.1703 \times 10^{-2}$ $\quad d = 5.4094 \times 10^{-2}$

$b = 1.1521 \times 10^{-3}$ $\quad e = 1.0725 \times 10^{-4}$

$c = -1.2605 \times 10^{-3}$

* Formerly Scott Research Laboratories, Inc.

where

L'_D = Estimate of displaced loss, gms/gal.

P_V = Reid vapor pressure of fuel, psi.

T_D = Average dispensed fuel temperature, °F.

T_T = Initial tank fuel temperature, °F.

This expression explained 94.5% of the variance in the displaced loss data and had a standard error of 5.6%. The expression was not directly suitable for use in the model because estimation of dispensed and tank fuel temperatures would be difficult. A field study was conducted to develop an expression for dispensed fuel temperatures in terms of more conveniently determined variables. Data were obtained in the summer and spring in the San Bernardino-Ontario area and in the winter in the Minneapolis-St. Paul area. The following expression was derived through stepwise multiple regression of a number of variables:

$$T_D = f + g\,T_U + h\,T_A$$

$f = -1.17523$

$g = 0.80785$

$h = 0.22667$

where

T_U = Underground fuel temperature, °F.

T_A = Ambient temperature, °F.

This expression explained 98.9% of the variance and had a 2.47% standard error of estimate. The variables T_U and T_A are convenient to measure and the expression could be used to eliminate T_D from the displaced loss equation.

From the Coordinating Research Council CAPE-5-68 program which studied the temperatures of automotive fuel systems under different driving patterns (Reference 7) it was estimated that:

$T_T = T_A + \Delta T$ where $T = 7°F$

This expression allowed the elimination of T_T from the displaced loss equation. The resulting expression gave the displaced hydrocarbon loss in terms of the desired variables, the Reid vapor pressure and the underground fuel and ambient temperatures.

The third year field study also provided values for the relative frequency of refueling operations as a function of the time of day.

The regional model is shown in the attached table. Its general form is a product of three terms. The first term is the regional average hydrocarbon refueling loss per gallon of fuel dispensed in the region for a given hour. The second term is the fraction of total daily refuelings which occur in that hour. By performing a summation of the product of these two terms over all hours of refueling operations in a day (16 hours), the total refueling loss per gallon for each day of the period is obtained. Multiplying by the third term, which is the average number of gallons dispensed per day for the period, and summing over days yields the total hydrocarbon refueling loss.

An error analysis of the overall model showed that the inherent error was about 14%. A sensitivity analysis indicated average errors of about 18% to be possible from misestimation of the input variables. It was further shown that application of the model, or the equations from which it was derived, to individual refueling operations could incur substantially larger errors.

The range of applicability of the model in terms of its input variables is:

Rvp	Range of Functions $T_A + 7$ and $0.81\ T_U + 0.23\ T_A - 1.2$
7	50 - 90
10	40 - 80
13	30 - 70

A computer program was written for convenient application of the model. Simplified forms of the model suitable for use with desk calculators were also demonstrated.

REGIONAL MODEL FOR HYDROCARBON REFUELING LOSSES FROM PASSENGER CARS

$$L'_T = \frac{\bar{G}}{453.6} \sum_{j=1}^{D} \sum_{i=1}^{H} R(h_i) \left(\bar{L}'_S + \bar{L}'_D (h_i, d_j) \right)$$

$$\bar{L}'_S = 0.30$$

$$\bar{L}'_D (h_i, d_j) = \exp(C_1 + C_2 \bar{P}_V(d_j) + C_3 \bar{T}_A(h_i, d_j) + C_4 \bar{T}_U(d_j) + C_5 \bar{P}_V(d_j)\, \bar{T}_A(h_i, d_j)$$

$$+ C_6 \bar{P}_V(d_j)\, \bar{T}_U(d_j) + C_7 \bar{T}_A(h_i, d_j)\, \bar{T}_U + C_8 \bar{T}_A^2(h_i, d_j))$$

$C_1 = -1.0141 \times 10^{-1}$
$C_2 = 5.2740 \times 10^{-2}$
$C_3 = -1.2164 \times 10^{-3}$
$C_4 = 6.0649 \times 10^{-4}$
$C_5 = 2.6115 \times 10^{-4}$
$C_6 = 9.3072 \times 10^{-4}$
$C_7 = 8.6642 \times 10^{-5}$
$C_8 = 2.4310 \times 10^{-5}$

where

L'_T = Estimated total hydrocarbon refueling loss for region over D days, pounds.

$\bar{L}'_S$ Estimated average spill loss, gms/gal dispensed.

$\bar{L}'_D$ = Estimated average displaced hydrocarbon loss, gms/gal dispensed.

$\bar{G}$ = Average daily volume of fuel dispensed within the region for the period, gallons.

D = Total integral days in specified period.

H = Total integral number of hours of refueling operations per day (fixed for period).

$R(h_i)$ = Fraction of total daily refueling operations which occur in h_i-th hour.

$\bar{T}_U$ = Regional average underground fuel temperature on a given day, °F.

$\bar{T}_A$ = Regional average ambient temperature for a given hour, °F.

$\bar{P}_V$ = Regional average Reid vapor pressure on a given day, psi.

Regional Model, continued

and where:

R_1 (0600-0700) = 0.0175
R_2 (0700-0800) = 0.0435
R_3 (0800-0900) = 0.0445
R_4 (0900-1000) = 0.0585
R_5 (1000-1100) = 0.0605
R_6 (1100-1200) = 0.0700
R_7 (1200-1300) = 0.0715
R_8 (1300-1400) = 0.0695
R_9 (1400-1500) = 0.0755
R_{10} (1500-1600) = 0.0770
R_{11} (1600-1700) = 0.0765
R_{12} (1700-1800) = 0.0835
R_{13} (1800-1900) = 0.0845
R_{14} (1900-2000) = 0.0775
R_{15} (2000-2100) = 0.0550
R_{16} (2100-2200) = 0.0350

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16. Abstracts

This report documents the final year of a three year study of hydrocarbon emissions during the refueling of passenger vehicles. The objective of the third year was the development of a mathematical model for estimating the total hydrocarbon losses from refueling operations for an air quality control region over a specified period of time. In order that the model could be used readily by community planners and other it was based on relatively easily obtained variables such as average Reid vapor pressure of the gasolines used in the region and average underground fuel and ambient temperature.

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Reid Vapor Pressure

17c. COSATI Field/Group: 13B; 07C; 13F; 15E;

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1.0 INTRODUCTION

1.1 The Problem

Compared to motor vehicle tailpipe emissions, a source of hydrocarbon air pollution which has received little attention is the hydrocarbon losses that result from the refueling of passenger cars. The losses encountered during refueling operations include:

1. Displaced fuel tank vapor.
2. Entrained fuel droplets in the displaced vapor.
3. Liquid spillage from the tank.
4. Liquid spillage from the nozzle.

Of these four loss sources, only the first (displaced fuel tank vapor) has been estimated for passenger cars.

During the filling of vehicle fuel tanks, splashing of the fuel accelerates vaporization and also produces small droplets which may be lost by entrainment. While little work had been done on this phenomenon in passenger vehicle-fuel tanks, a considerable amount of work was done by the petroleum industry on the splash filling of petroleum tanks and transportation equipment (References 1, 2, and 3).

Reference 3 concludes that faulty tank design or poorly conducted refueling of petroleum tanks could result in entrainment losses two to three times greater than the loss due to displaced vapor. However, this conclusion cannot be extended to the refueling of automobile gas tanks, because of the differences in the tank sizes, refueling apparatus, and other equipment. A number of methods have been proposed for measuring the losses experienced in filling petroleum tanks (Reference 4). The accuracy of these methods was estimated to be about $\pm$25%.

A frequent cause of liquid spillage is overfilling of the tank, resulting in fuel being forced back up the fuel fill pipe. Some vehicles will "spit-back" liquid fuel even before the tank is full.

Thus, although the sources of passenger car hydrocarbon refueling losses had been recognized, little was known about the magnitude and relative frequency of occurrence of each of these sources of hydrocarbon loss.

Before a meaningful assessment of the importance of these losses could be made, it was necessary to conduct a field survey of gasoline stations so as to determine the magnitudes and frequency of occurrence of these refueling losses.

1.2 Program Background

With mutual concern for the foregoing problem, meetings were held by the Air Pollution Research Advisory Committee (APRAC) of the Coordinating Research Council (CRC) and the National Air Pollution Control Administration of the U. S. Department of Health, Education, and Welfare (now the Office of Air and Waste Management of the Environmental Protection Agency) to initiate an investigation of passenger car refueling losses. This problem fell within the scope of the newly created APRAC-CAPE-9 Committee which was charged with studies of refueling losses in general.

On December 18, 1968 Scott Research was awarded a contract to conduct an "Investigation of Passenger Car Refueling Losses".

1.3 First-Year Program

The first-year program was conducted in two phases. The first phase was an experimental study carried out in the laboratory to determine the amount of the hydrocarbon losses from displaced vapor and spillage. The second pahse was a field survey of service stations to determine the frequency of occurrence of gasoline spills. The laboratory study was initiated upon award of the contract. Go-ahead for the field survey was subsequently received on April 16, 1969.

The laboratory study yielded information on the effect of fuel tank configuration, fill rate, vapor pressure, and fuel and vapor temperatures on the displaced vapor and entrained droplet losses. Additional data were obtained on the average spill loss for different fuel tank configurations filled at different fueling rates. The minimum, maximum, and average amounts of nozzle drip were determined by measurement.

In order to carry out the laboratory study, Scott constructed two enclosures: (1) a full-sized SHED (acronym for Sealed Housing for Evaporative Determinations) to collect spillage from an entire automobile, and (2) a

MINISHED to collect displaced losses from fuel tanks alone. Measurements of hydrocarbon concentrations in both SHEDs were made with a flame ionization detector (FID).

The field survey was carried out in two parts. The first part utilized Scott employees who filled-out a questionnaire each time they refueled their automobiles. This questionnaire was filled-out without the attendant's knowledge. In the second part, Scott technicians surveyed several stations in the San Bernardino area for spillage and nozzle drip under the guise of determining the average amount of gasoline per fill. A coded data form allowed the technician to record number of spills and nozzle drips without an attendant's knowledge.

Significant factors contributing to individual and overall refueling losses were examined and discussed in the first-year report, but the scope of the first-year program was limited to the results of exploratory laboratory tests and a small sample of survey observations (Reference 5).

1.4 Second-Year Program

The CAPE-9 Committee concluded that an expanded field survey was necessary to supplement the relatively small sample size on which the results of the first-year program were based. Improvements in the techniques and equipment used to measure displaced losses in the laboratory were also desired. On November 19, 1969, the CRC requested Scott to propose a one-year extension to the original program. Scott responded on December 16, 1969, and program go-ahead was received on June 30, 1970.

Refueling operations were observed in five major cities during each of the four seasons. Detailed information was obtained on the magnitude and frequency of spill losses in the service station environment. Data were obtained at one service station in each city on dispensed fuel, displaced vapor, underground fuel and ambient temperatures during refueling operations. Laboratory studies were conducted on the effect on displaced hydrocarbon losses of: gasoline volatility (as measured by Reid vapor pressure), dispensed fuel temperature, tank fuel temperature, displaced vapor temperature, ambient temperature, fuel tank filler pipe configuration and refueling procedures.

From the field survey data it was estimated that the average total spill loss was 3.5 grams per refill. Based on an observed average of 11.5 gallons of gasoline dispensed per refill this estimated spill loss could also be expressed as 0.30 grams per gallon dispensed.

Regression analyses conducted on the laboratory data yielded a mathematical expression relating displaced hydrocarbon losses to average dispensed fuel temperature, average displaced vapor temperature and the Reid vapor pressure (RVP) of the fuel. This expression when combined with the temperature data obtained during the survey and the average RVP for the fuels used in the survey cities yielded the estimate that the average displaced loss of hydrocarbon vapors was 57.4 grams per refueling operation or 5.0 grams per gallon dispensed. The average total refueling loss based on the survey and laboratory data was, therefore, estimated at 5.3 grams per gallon of dispensed gasoline. On the assumption of a national average of 13.4 miles per gallon the estimated loss could be expressed as 0.4 grams hydrocarbon refueling losses per vehicle mile. (Reference 6)

1.5 Third-Year Program

The CAPE-9 Committee established as the objective for the third year program the development of a mathematical model (with associated computer program) for estimating the total hydrocarbon losses from refueling operations for a specific air quality region during a specified period of time. In order that the model be readily used by community planners and others it was to be based on relatively easily obtained or estimated variables such as ambient temperature, underground fuel temperature, Reid vapor pressure and gasoline consumption for the region. To develop the model it was necessary to know the magnitude of spill losses and the mathematical relationship of hydrocarbon (HC) displaced from the fuel tank during refueling to the above mentioned variables. Information on the frequency of refueling operations by day of the week and hour of day was also needed.

The second year program provided a good estimate of spill losses for use in the model. However, the mathematical relationship developed in the second year for displaced HC losses was judged inadequate for use in the

model because it was based on an incomplete data set and a too narrow range of fuel Reid vapor pressures. The laboratory program was, therefore, redone in the third year with an improved experimental design. A new mathematical expression was derived from the new data by stepwise multiple regression analysis and related displaced HC losses to average dispensed fuel temperature, initial vehicle fuel tank temperature and the RVP of the fuel.

In order to transform the laboratory expression for displaced HC vapor losses into a mathematical expression containing the more conveniently obtained field variables, underground fuel temperature, ambient temperature and RVP, additional temperature data were obtained in the field during actual vehicle refuelings. The data were obtained at service stations in the San Bernardino-Ontario area in summer and spring and in the Minneapolis-St. Paul area in the winter. Multiple regression analysis of the field data led to an expression relating dispensed fuel temperature to underground fuel and ambient temperatures. The substitution of this expression into the laboratory based expression eliminated the dispensed fuel temperature from the expression. A simple linear expression relating initial fuel tank temperature to ambient temperature based on data obtained during the Coordinating Research Council CAPE-5 program was used to eliminate the initial dispensed fuel tank temperature from the expression. The resulting transformed expression related the displaced HC vapor losses to the desired variables, ambient temperature, underground fuel temperature and RVP. This expression along with the estimate of spill losses was used in combination with data on refueling frequencies obtained in the San Bernardino-Ontario and Minneapolis-St. Paul areas to develop the desired air quality region model. The detailed program and development of the model are documented in the following sections of this report.

2.0 LABORATORY STUDY

The purpose of the laboratory study was to develop a new, improved mathematical expression relating displaced hydrocarbon (HC) losses during refueling to average dispensed fuel temperature, initial tank fuel temperature and fuel Reid vapor pressure (RVP).

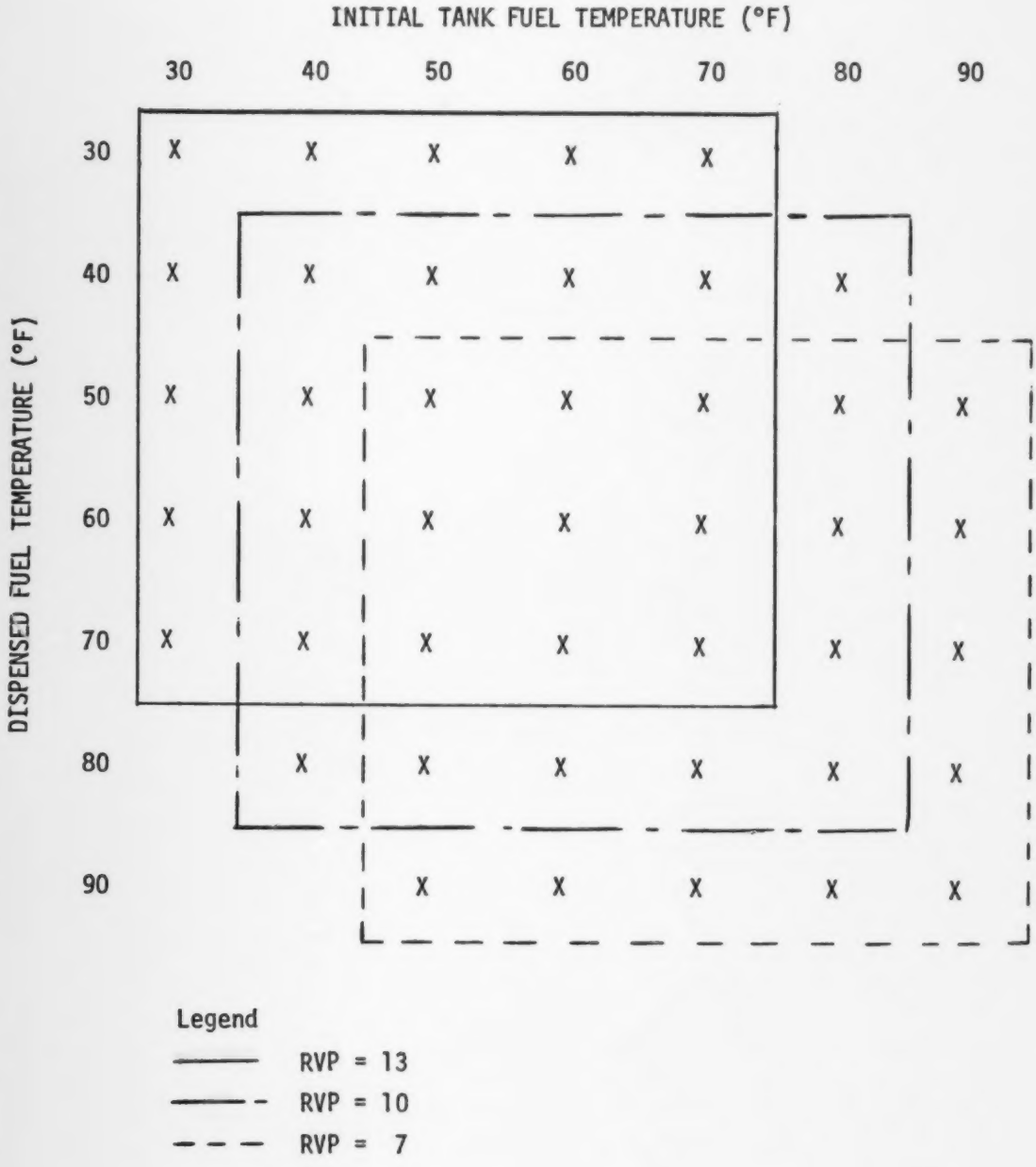
2.1 Experimental Design

In the second year program it was determined that the displaced HC loss could be expressed as a function of the following significant independent variables: the fuel RVP, the average dispensed fuel temperature and either the average displaced vapor temperature or initial vehicle tank fuel temperature. However, because of an incomplete data base and the use of fuels with too narrow a range of Reid vapor pressures, the regression expressions derived in the second-year study were judged inadequate for use in developing an air quality region model. It was, therefore, necessary in the third year program to completely redo the laboratory study to obtain a new set of data which would serve as the basis for deriving a more reliable mathematical expression. The experimental design of the study provided for both an adequate data base and a sufficient range of the independent variables to meet this objective.

Displaced hydrocarbon losses were measured with the Scott MINISHED operating under carefully controlled conditions in the Scott all-weather room. The procedures used were those developed during the first two years of the program and are fully described in References 5 and 6.

The experimental design is shown in Figure 2-1. It is seen that the controlled variables are average dispensed fuel temperature, initial tank fuel temperature, and the fuel RVP. Five levels each of dispensed fuel temperature and initial tank fuel temperature were used for each of three levels of RVP. Each experiment was replicated so that a total of 150 experiments was conducted. The results from ten of these experiments had to be discarded because of instrumentation or other problems, leaving a sample of 140 measurements of displaced hydrocarbon vapor loss available for mathematical analysis.

Figure 2-1 Experimental Design of Laboratory Measurement of Displaced Hydrocarbon Losses



The experimental design represents the optimum desired levels of each independent variable. In conducting the actual experiments it was not always possible to achieve the exact levels required by the design. For example, heating and dispensing the fuel resulted in some cases in dropping the RVP from 13 psi to 12.2 psi. Thermocouple and other instrumentation differences also introduced variability.

Four gallons of fresh fuel were dispensed into the fuel tank one-half hour prior to each experiment. This time was determined to be adequate to saturate the vapor space and assure that the vapor composition and fuel RVP in the tank were at the desired values at the beginning of each test. Ten gallons of fuel were then dispensed during each experiment. A sample of the dispensed fuel was obtained for each experiment by the displaced water method. In this technique a gasoline sample is pulled into a glass jar by the siphoning action of ice water being displaced from the jar. The tightly stoppered jars were transported packed in ice to an Ethyl Corporation laboratory for measurement of RVP. Fresh fuel was used in each experiment. Inspection data for each of the three fuels are given in Appendix A.

The data obtained in the 140 valid runs are given in Appendix B. The data include the measured values for each run of the independent variables: average displaced fuel temperature, initial tank fuel temperature and fuel RVP, and the dependent variable, displaced HC loss. Although not used in the data analysis the MINISHED ambient temperature are also recorded.

2.2 Derivation of New Regression Model for Estimating Displaced Hydrocarbon Losses

The regression analysis conducted during the second year program established that an appropriate functional form for the desired model was obtained by expressing the displaced HC loss as an exponential function of the independent variables. A linear model suitable for the application of multiple regression techniques was therefore obtained by regressing the natural logarithm of the displaced HC against linear combinations of the independent variables, cross products of the variables and higher power terms.

Four independent variables were chosen for the analysis. These were the three design variables fuel RVP, average dispensed fuel temperature, and the initial tank fuel temperature plus the MINISHED ambient temperature. In the initial phases of the analysis all combinations of first, second, and third order terms of these four variables were examined using the techniques of stepwise multiple regression analysis. Four terms were finally identified as providing an efficient fit to the data. In the order of decreasing contribution to reduction in unexplained variance these were: the product of RVP and average dispensed fuel temperature, initial tank fuel temperature, RVP, and the product of average dispensed fuel temperature and initial tank fuel temperature.

A summary of the stepwise regression of these four terms is shown in Table 2-1. The correlation matrix is given in Table 2-2. It is seen from Table 2-1 that with all four terms included in the regression expression the multiple correlation coefficient, R between the measured displaced HC loss and the independent variables has the value R = 0.972. The coefficient of determination, R^2, which gives the fraction of variance in the data accounted for by the regression relationship is 0.945. Thus 94.5% of the variance has been explained. It is interesting to note from the Step 1 results that about 85% of the variance is accounted for by the product of the average dispensed fuel temperature and the RVP. It is also seen from the first row of the correlation matrix in Table 2-2 that none of the other terms taken alone correlate nearly as well with the natural logarithm of

Table 2-1 Summary of Stepwise Regression Analysis of Laboratory Displaced Hydrocarbon Losses Data

Step	Variable	Regression Coefficient	Std. Error of Coefficient	Multiple R	Multiple R^2	Std. Error of Estimate
1	Constant	3.7581×10^{-1}				
	RVDA	1.8126×10^{-3}	6.5312×10^{-5}	0.921	0.848	0.092
2	Constant	1.2775×10^{-1}				
	RVDA	1.8380×10^{-3}	$5\ 0857 \times 10^{-5}$			
	TK	4.0042×10^{-3}	4.1926×10^{-4}	0.953	0.909	0.072
3	Constant	-6.5063×10^{-2}				
	RVDA	1.6453×10^{-3}	5.6828×10^{-5}			
	TK	5.8259×10^{-3}	4.9365×10^{-4}			
	RV	2.0266×10^{-2}	3.5367×10^{-3}	0.963	0.927	0.065
4	Constant	-9.1703×10^{-2}				
	RVDA	1.1521×10^{-3}	8.9285×10^{-5}			
	TK	-1.2605×10^{-3}	1.1507×10^{-3}			
	RV	5.4094×10^{-2}	5.9545×10^{-3}			
	DATK	1.0725×10^{-4}	1.6154×10^{-5}	0.972	0.945	0.056

Model: $\ln L'_D = a + b\,RVDA + c\,TK + d\,RV + e\,DATK$

where: L'_D = Estimate of displaced loss, gms/gal

RVDA = Product of Reid vapor pressure (psi) and average dispensed fuel temperature, (°F)

TK = Initial tank fuel temperature, (°F)

RV = Reid vapor pressure, (psi)

DATK = Product of average dispensed fuel temperature, (°F), and tank fuel temperature, (°F)

Table 2-2 Correlation Matrix of Regression Variables - Laboratory Displaced Hydrocarbon Losses Measurements

Variable Number	LNLOSS	RVDA	TK	RV	DATK
1	1.000	0.921	0.198	0.423	0.284
2		1.000	-0.052	0.512	0.081
3			1.000	-0.579	0.915
4				1.000	-0.683
5					1.000

Variable Number	Variable Symbol	Identification
1	LNLOSS	Natural logarithm of displaced HC loss, $\ln\left(\frac{gms}{gal}\right)$
2	RVDA	Product of RVP and average dispensed fuel temperatures, psi x °F
3	TK	Initial tank fuel temperature, °F
4	RV	RVP, psi
5	DATK	Product of average dispensed fuel and initial tank fuel temperatures, $(°F)^2$

the displaced loss. Since the displaced vapor comes into close contact with the incoming fuel as it passes out the filler neck and since the fuel volatility is important in determining the amount of hydrocarbon in the displaced gases, it would be expected that the dispensed fuel temperature and the RVP are of major importance. The regression analysis shows that the impact of each of these variables depends on the magnitude of the other. This also appears reasonable in that the vapor pressure of a liquid increases approximately exponentially with temperature. The remaining terms of the expression have no obvious technical interpretation.

The standard error of estimate for the natural logarithm of the displaced HC loss is 0.056. It is shown in Appendix C that this can be interpreted as a 5.6% error percentage in the displaced HC loss. The ability of the regression to estimate the losses observed in the MINISHED experiments is shown in Figure 2-2. It may be concluded from the statistical measures and from an examination of the Figure that the regression expression provides a good fit to the experimental data:

The model for displaced hydrocarbon losses derived from the regression analysis is, therefore:

$$\text{Ln } L'_D = a + bP_V T_D + cT_T + dP_V + eT_D T_T \qquad (2\text{-}1)$$

Where L'_D = Estimate of displaced hydrocarbon loss, gms/gal of dispensed fuel

P_V = RVP of fuel, psi

T_D = Average dispensed fuel temperature, °F

T_T = Initial tank fuel temperature, °F

$a = -9.1703 \times 10^{-2}$

$b = 1.1521 \times 10^{-3}$

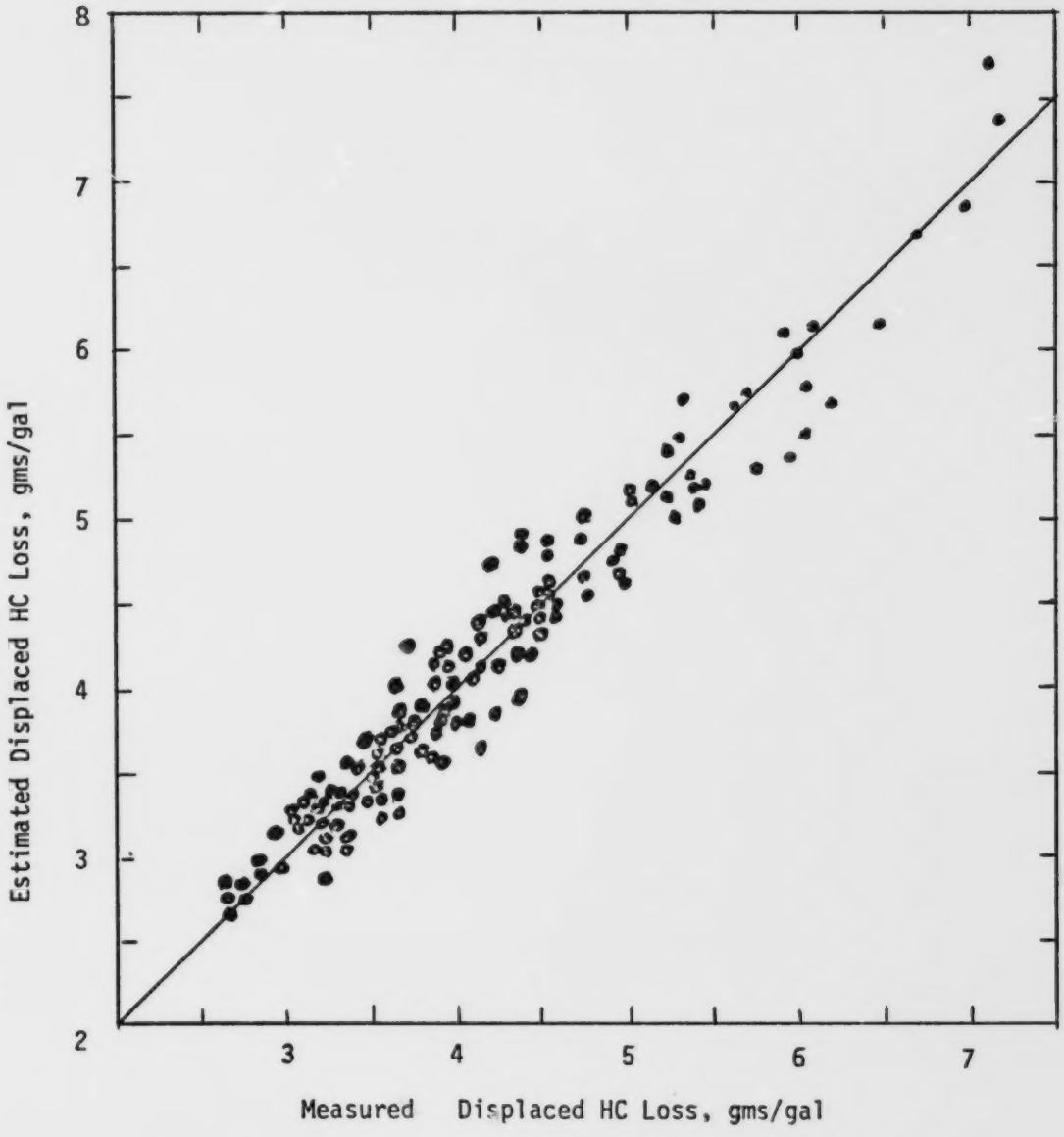
$c = -1.2605 \times 10^{-3}$

$d = 5.4094 \times 10^{-2}$

$e = 1.0725 \times 10^{-4}$

In using Equation (2-1) certain constraints must be observed. The regression model should not be extrapolated beyond the values of the input

Figure 2-2 Measured Versus Estimated Displaced Hydrocarbon Losses



data. For example, an RVP of 13 psi should not be used when the dispensed fuel temperature is greater than 70°F. Conversely, when the dispensed fuel temperature is 30°F, the RVP should not be taken as, say 7 psi. These constraints result not only from the experimental data base but reflect the fuel RVP's actually provided in the field for the various temperature ranges.

It is also important to realize that the data base contains no data at temperatures below 30°F or in excess of 90°F. Estimates of displaced vapor loss should not, therefore, be made at extremely low or high temperatures since the estimate would be suspect. There is good reason to suspect that, as the temperature approaches the initial boiling point of the fuel, the relationship described by Equation (2-1) will become invalid.

In summary the correlation holds for fuels whose RVP's are in the range 7 to 13 psi while the range of allowable temperatures for a given RVP are:

RVP (psi)	Temperature Ranges of Dispensed and Tank Fuels (°F)
7	50 - 90
10	40 - 80
13	30 - 70

Other considerations, which will be discussed in more detail in Section 4.4, further limit the range of applicability of Equation (2-1). The model applies most accurately to the following situations:

- o RVP of the tank fuel and the dispensed fuel are the same.
- o Negligible weathering of tank fuel.
- o Fuel tank has the same configuration as that used in the study.
- o Refuelings which start with a few gallons of fuel in the tank. and stop with the tank slightly over half full.

3.0 FIELD SURVEY

The field survey conducted in the third year program had two objectives: first, to collect temperature data at service stations during refueling of vehicles in order to establish a mathematical relationship between the temperature of dispensed fuel and the ambient and underground fuel temperatures; second, to determine how the number of refueling operations per hour varied with time of day and day of week. The mathematical relationship and refueling frequency data obtained from the field study were to be used in combination with the displaced hydrocarbon loss expression obtained from the laboratory study (Section 2.0) to develop the region wide model (Section 4.0).

3.1 Description of Field Survey

The field survey phase collected data for three ranges of ambient temperature, T_A:

1. Maximum $T_A \leq 30°F$
2. $60° \leq$ Maximum $T_A \leq 80°F$
3. Maximum $T_A \geq 90°F$

For each service station surveyed, at least two dispensers on each of two islands were instrumented (See Reference 6 for details of experimental set-up) to measure the dispensed fuel temperature and the displaced vapor temperature each time a dispenser was used. In addition, the following data were obtained for all refueling operations and all dispensers:

1. Time of day.
2. Time between refueling operations.
3. Gallons of fuel dispensed.
4. Exposure of dispenser to sun.

The ambient temperature, relative humidity, and barometric pressure were continuously measured with instruments mounted in a "cotton-region type" weather shelter. The underground fuel temperature was measured every two hours.

Data collection operations were conducted for seven days, two shifts per day, at each of four stations in the San Bernardino-Ontario area during the summer. Data were collected in the Minneapolis-St. Paul area for seven days, two shifts per day, at each of two stations during the month of January to obtain cold weather data. Finally, because of budget considerations, data were collected for one week at one station on a one-shift basis in San Bernardino during the spring to obtain moderate temperature data.

The stations were selected with respect to two configurational criteria: 1) canopy vs no canopy, and 2) pump in tank vs pump above-ground. It was conjectured that these parameters might be a factor in the relationship of dispensed fuel temperature to ambient temperature and underground fuel temperature. Other factors such as the depth and length of subsurface fuel lines and the material used to pave the station's apron may also influence the dispensed fuel temperature but no data were obtained that would permit an evaluation of these factors.

3.2 Regression Analysis of Temperature Data

A sampling of temperature data for three selected days corresponding to summer, spring, and winter are given in Appendix D. Stepwise multiple regression analyses were run on 2637 field temperature observations. The average dispensed fuel temperature was regressed against underground fuel temperature, ambient temperature, canopy vs no canopy, pump in tank vs. pump above ground, gallons of fuel dispensed, and time between dispenser use. The analysis showed that only the underground fuel temperature and ambient temperature led to significant reductions in unexplained variance of the dispensed fuel temperature. Therefore, only the temperature variables were retained for further analysis. It must be noted, however, that a much larger program with an appropriate experimental design, would be required to provide a definitive conclusion regarding the influence of the

variables that were dropped. Such a program should also include additional configruational variables such as mentioned above.

Table 3-1 summarizes the stepwise regression and Table 3-2 the correlation matrix of the temperature variables. Further details of the analysis are shown in Appendix E. It is seen that 98.9% of the variance in the average dispensed fuel temperature is accounted for with a standard error of estimate of 2.47°F. Table 3-1 shows that the underground fuel temperature alone accounts for 98.2% of the variance. Addition of the ambient temperature term appears to be merited in view of the further lowering of unexplained variance from 1.8% to 1.1% a large proportional improvement, and the 23% improvement in the standard error of estimate. The correlation matrix shows that ambient temperature taken alone can account for 89% of the variance in the dispensed fuel temperature. It also shows, as would be expected, that the underground fuel and ambient temperatures when taken over all seasons of the year are highly correlated.

Since the data base used in the regression analysis consisted of three subsets of data each representing a different city/month combination, it was of interest to see what regression analyses of these individual sets of data would yield. The results are summarized in Table 3-3 and given in more detail in Appendix E. The percentage of variance accounted for in the individual subset analyses are much smaller than for the complete set. This result is largely accounted for by the restricted ranges of the variables, particularly the underground fuel temperature whose standard deviation was one to two degrees in each of the subsets. The standard error in each case is about the same as for the regression analysis on the total sample. From the more detailed analysis in Appendix E it will be seen that the ambient temperature accounts for most of the variance in the dispensed fuel temperature for the high and moderate temperature data. For the low temperature subset the underground fuel temperature is again the dominant variable in accounting for variance of the dependent variable. These observations are accounted for by the very restricted range of underground fuel temperatures in the high and moderate temperature data and the relatively greater range of this variable in the low temperature subset.

Table 3-1 Summary of Stepwise Regression Analysis of Third Year Field Survey Temperature Data

Step	Variable	Regression Coefficient	Std. Error of Coefficient	Multiple R	Multiple R^2	Std. Error of Estimate
1	Constant	-1.21315				
	UF	1.01714	0.00271	0.991	0.982	3.21
2	Constant	-1.17523				
	UF	0.80785	0.00530			
	AM	0.22667	0.00529	0.995	0.989	2.47

Model: $DA = a + b\,UF + c\,AM$

where DA = Estimate of average dispensed fuel temperature, °F
UF = Underground fuel temperature, °F
AM = Ambient temperature, °F

Table 3-2 Correlation Matrix of Regression Variables - Field Survey Temperature Measurements

Variable Number	DA	UF	AM
1	1.000	0.991	0.946
2		1.000	0.920
3			1.000

Variable Number	Symbol	Identification
1	DA	Average dispensed fuel temperature, °F
2	UF	Underground fuel temperature, °F
3	AM	Ambient temperature, °F

Table 3-3 Summary of Stepwise Regression Analyses of Subsets of Third Year Field Survey Temperature Data

Subset	Variable	2 σ Temp. Range, °F	Regress. Coeff.	Std. Error of Coeff.	Multiple R	Multiple R^2	Std. Error of Estimate
Minneapolis-	Constant		-11.37380				
St. Paul	DU	24-38	1.10383	0.03014			
Winter	AM	12-45	0.27503	0.01283	0.862	0.743	2.77
San	Constant		33.11020				
Bernardino	DU	65-69	0.15295	0.13333			
Spring	AM	41-76	0.35165	0.01672	0.843	0.711	1.95
San	Constant		38.81367				
Bernardino	DU	82-87	0.34232	0.04311			
Summer	AM	59-97	0.21989	0.00545	0.743	0.552	2.05

Model $DA = a + b\,DU + c$

where DA = Estimate of average dispensed fuel temperature, °F
DU = Underground fuel temperature, °F
AM = Ambient temperature, °F

Within each of the three subsets there is little correlation of ambient and underground fuel temperatures. This comes about because within each season there is a relatively small change in average ambient temperature. The underground fuel temperature is more influenced by the average ambient temperature than by the day to day variations of ambient about its mean. This observation together with those of the preceeding paragraph emphasizes the importance of including an ambient temperature term in the regression for the total set even though the underground fuel temperature is by far the dominant variable.

The regression expressions for the subsets shown in Table 3-3 bear little resemblance to the expression in Table 3-1 for the total data set. To compare how well the expression for the composite agrees with the expressions for the individual subsets comparative calculations were made for a spread of temperatures of three standard deviations about the mean in each temperature regime and are shown in Table 3-4. It is seen that the agreement is excellent for the high temperature case. For the low temperature case the agreement is close only at the means of the temperature data. At the extremes the two expressions are $\pm$ 4°F apart. In the moderate temperature case there is a consistent descrepancy of 1 to 3° over the range of the data. Part of the reason for these differences is accounted for by the fact that there are 660 sets of observations for the low temperature case, 187 sets of observations for the moderate temperature, and 1790 sets of observations for the high temperature case. In deriving the composite equation no attempt was made to compensate for the smaller number of low temperature and still smaller number of moderate temperature observations. Thus the high temperature data weigh most heavily. The low temperature data are the next most dominant which accounts for the good agreement at the mean of the low temperatures. The two extreme sets, therefore, largely determine the total expression and it is not surprising the moderate temperature set shows a consistently lower estimated dispensed fuel temperature. To summarize: the moderate temperature data points tend to fall below the plane of the total regression expression; the winter data points show a uniformly wide spread on either side of the plane; the

Table 3-4 Comparison of Dispensed Fuel Temperatures Estimated by Total Regression Expression and Individual Subset Expressions

Temperature Regime	Temperatures, °F				
	Underground Fuel	Ambient	Estimated Dispensed Fuel Composite	Subset	Difference
Low					
3σ high	41.1	53.5	44.2	48.7	-4.5
mean	30.6	28.3	30.0	30.2	-0.2
3σ low	20.1	3.1	15.8	11.7	4.1
Moderate					
3σ high	70.3	84.5	74.8	73.6	1.2
mean	67.0	58.7	66.3	64.0	2.3
3σ low	63.7	32.9	57.7	54.4	3.3
High					
3σ high	88.1	106.5	94.1	92.4	1.7
mean	84.5	78.0	84.8	84.9	-0.1
3σ low	80.9	49.5	75.4	77.4	-2.0

summer data points fall close to the plane; the total regression covers the overall range of data reasonably well but is not uniformly good for each of three data subsets. These differences are to be expected. The three subsets represent different service stations in different geographic locations. The coefficients of the regression equations are influenced, therefore, by factors in addition to the underground fuel temperature and ambient temperature. These might be depth and length of sub-surface lines, etc. The limited number of stations and cities studied prevented including such factors in the analysis.

From the analysis in the preceeding paragraph it is seen despite some uneven treatment of the three cases the overall expression gives a good representation of the total data set and, therefore, provides a suitable expression for developing the regional model. This expression is:

$$T_C = a + bT_U + cT_A, \qquad (3\text{-}1)$$

where T_D = Average dispensed fuel temperatue, °F

T_U = Underground fuel temperature, °F

T_A = Ambient temperature, °F

a = -1.17523

b = 0.80785

c = 0.22667

While there may be a temptation to use the individual expressions for estimates within a given season this practice is not advised. The individual expressions are based on very limited data and small ranges of the variables and their generality is far more subject to question than that of the overall expression.

3.3 Frequency of Refueling Operations

The temperature data were supplemented by the collection of data yielding the frequency of refueling operations by day of week and by hour of day, where a refueling day is 16 hours long. Since data were collected on a one-shift basis for Station 7, those operational data were not included in the frequency of refueling analysis. Figure 3-1 shows the frequency functions for operations by day of week for Stations 1 through 6 and Figure 3-2 shows the frequency function for the composite station. The dashed line in Figure 3-2 represents the average frequency for one week of operation. No day of the week was significantly different from the average (or even from any other day) as determined by t-testing. For modeling purposes, then, the days of the week may be taken to be indistinquishable.

The frequency function for refueling operations as a function of the 16-hour day for the composite station is shown in Figure 3-3 and tabulated in Table 3-5. Again, Station 7 data have been excluded because of the one-shift operation. The hour-by-hour frequencies in Table 3-5 are used in the regional model as shown in the next section.

Although not directly required for modeling purposes, it is of some interest to note the variation in fuel dispensed per operation. Figure 3-4 shows the frequency function for the number of gallons dispensed per refueling operation. The mean number of gallons is 10.4. The second-year field survey which covered other cities gave a value of 11.4 gallons. Thus, the average varies from city-to-city (Reference 6). It should, of course, be kept in mind that the frequency of fill by hour and day, and gallons per fill can vary by locale and also with time for a given location.

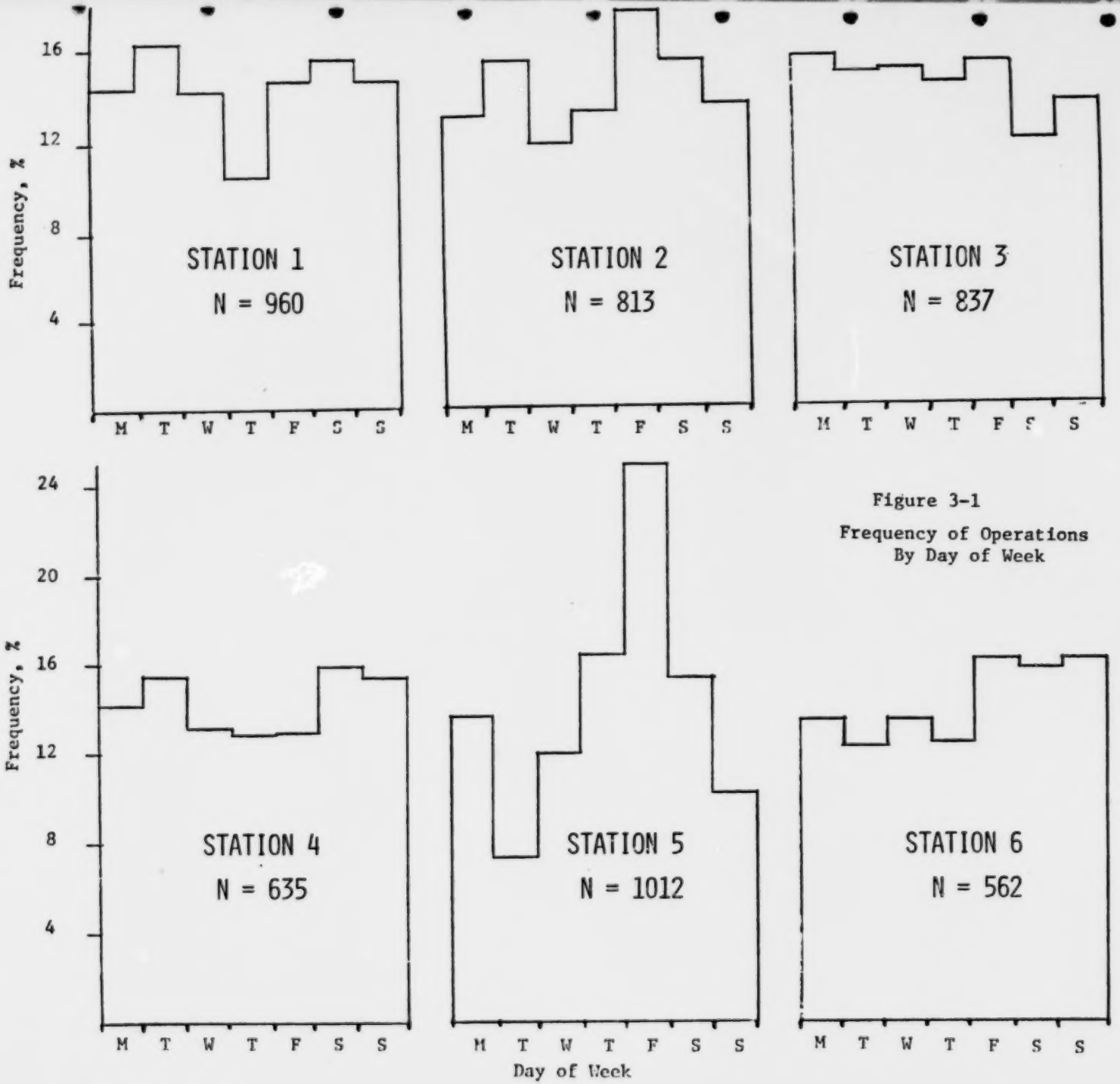


Figure 3-1

Frequency of Operations
By Day of Week

Figure 3-2

Frequency of Operations
By Day of Week

Composite Station

N = 4819

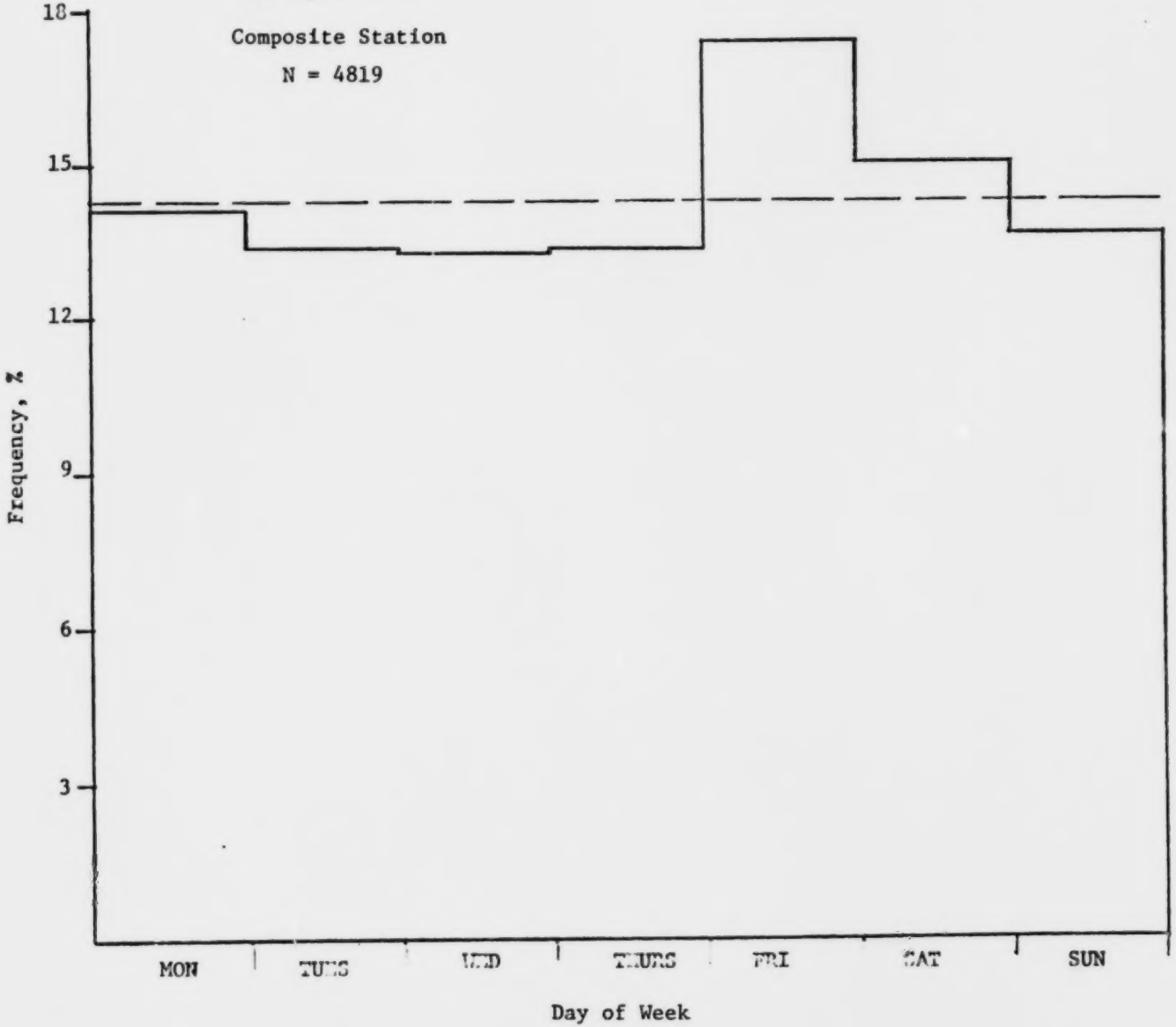
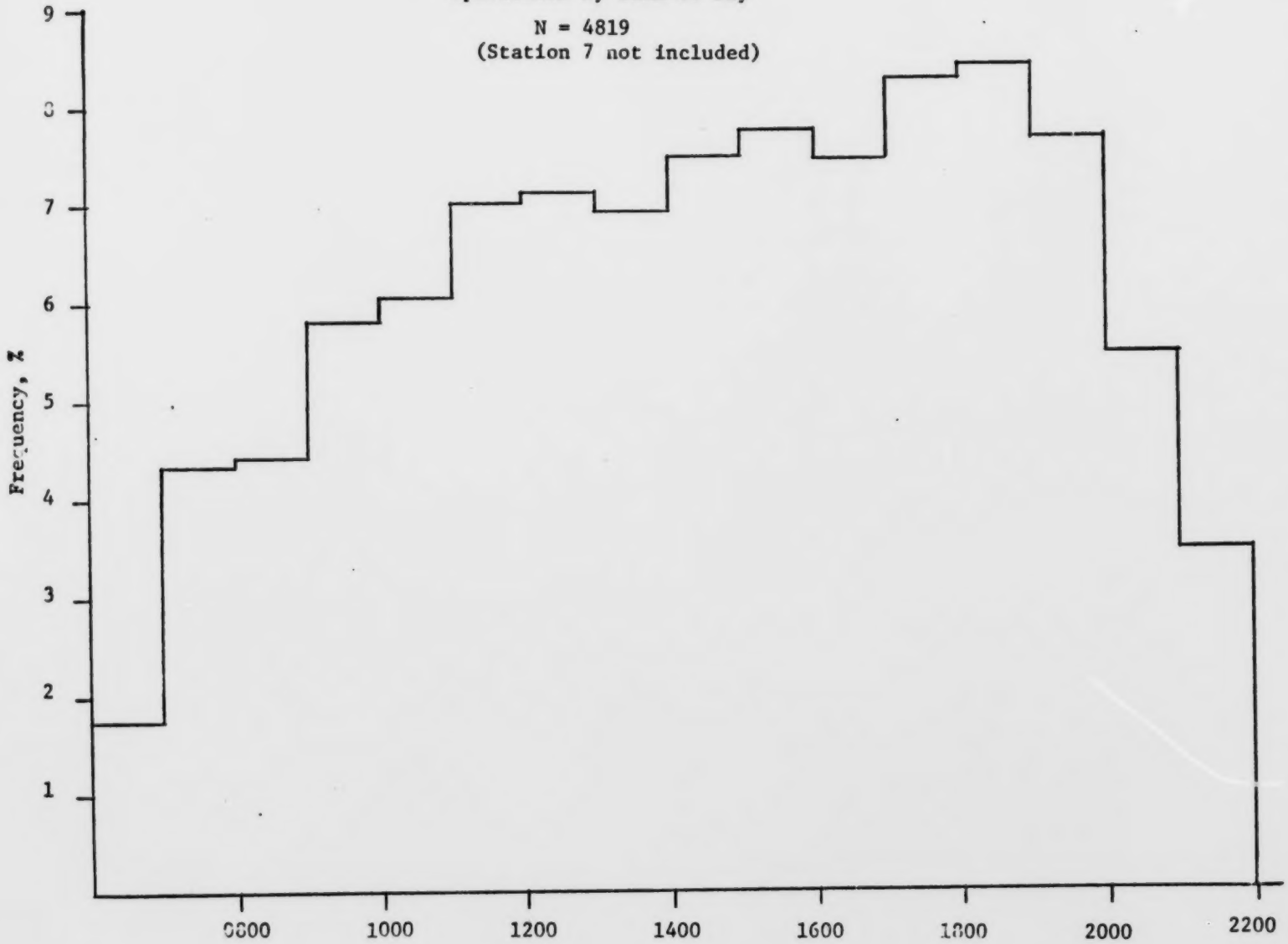


Figure 3-3

Frequency Function for Refueling Operations by Time of Day

N = 4819
(Station 7 not included)



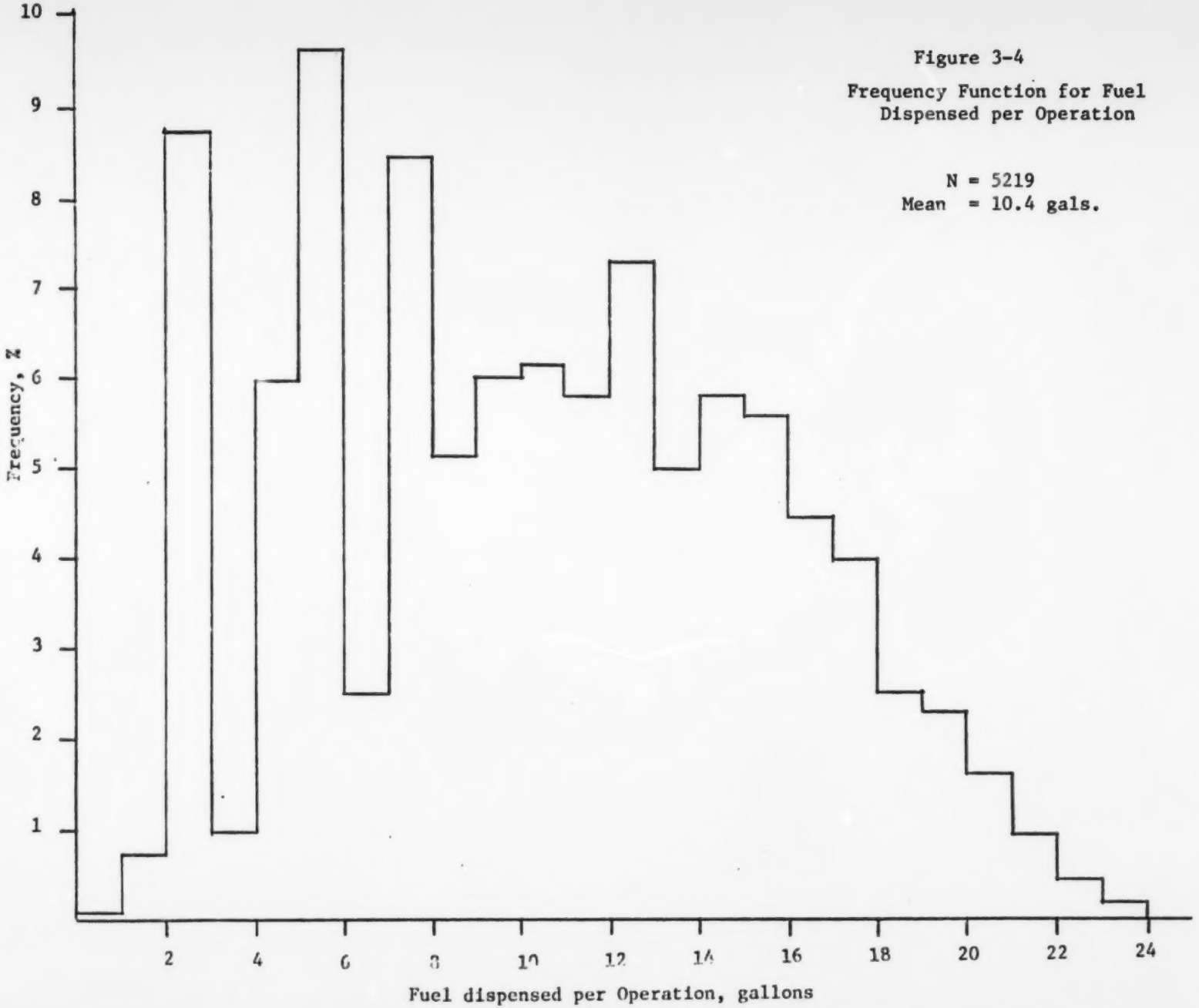


Figure 3-4

Frequency Function for Fuel Dispensed per Operation

N = 5219
Mean = 10.4 gals.

Table 3-5 Frequency Distribution of Refueling Operations per Hour From Six AM to Ten PM

Interval #	Hour Beginning at:	Fraction of Total Refueling Operations
1	6:00 AM	0.0175
2	7:00	0.0435
3	8:00	0.0445
4	9:00	0.0585
5	10:00	0.0605
6	11:00	0.0700
7	12:00	0.0715
8	1:00 PM	0.0695
9	2:00	0.0755
10	3:00	0.0770
11	4:00	0.0765
12	5:00	0.0835
13	6:00	0.0845
14	7:00	0.0775
15	8:00	0.0550
16	9:00	0.0350
		1.0000

4.0 REGIONAL HYDROCARBON REFUELING LOSS MODEL

This section derives a model for estimating hydrocarbon losses from refueling automobiles in a given geographic area over a specified period of time. It makes use of:

- Estimates of spilling losses during refueling operations obtained during the second year program.
- The regression expression derived in the third year program for displaced hydrocarbon losses as a function of fuel Reid vapor pressure, average dispensed fuel temperature, and initial tank fuel temperatures (Section 2).
- The regression expression derived in the third year program for average dispensed fuel temperature as a function of underground fuel temperature and ambient temperature (Section 3).
- A relationship between initial tank fuel temperature and ambient temperature taken from the Coordinating Research Council's CAPE-5 program which studied fuel system temperatures during vehicle operation.
- The distribution of refueling operations by hour from 6 AM to 10 PM obtained in the third year program field survey (Section 3).

The utility and limitations of the model are discussed and its application illustrated through use of a computer program and a desk calculator.

4.1 Derivation of Regional Model

The total hydrocarbon losses from the fueling of automobiles for a given geographic area over a specified number of days is the grand sum of the losses from each refueling operation conducted during the time period of interest. It is possible to order these losses by day and hour within the day in which they occur. We have, therefore:

$$L_T = \sum_{j=1}^{D} \sum_{i=1}^{H} \sum_{k=1}^{N(h_i, d_j)} L_R (n_k, h_i, d_j) \; G(n_k, h_i, d_j) \qquad (4.1)$$

where L_T = Total hydrocarbon refueling losses over D days for the region expressed in the same weight units as L_R

L_R = Loss in arbitrary weight units per unit volume of fuel dispensed in n_k-th refueling operation during the h_i-th hour of the d_j-th day.

G = Volume of fuel dispensed into vehicle during the n_k-th refueling in the h_i-th hour of the d_j-th day.

D = Total integral number of days for period.

H = Total integral number of hours of refueling operations per day (assumed the same for each day).

$N (h_i d_j)$ = Total number of refuelings that occurred in the h_i-th hour of the d_j-th day.

To transform this exact model into a practical, working model will require a number of assumptions, each of which can cause some loss of accuracy. The assumptions that are required and the derivation of a working model will be given in this subsection. Subsection 4.3 will discuss the potential errors which may be introduced by the assumptions.

Assumption #1 The loss L_R is not a function of volume of fuel dispensed.

Assumption #2 The gallons of fuel dispensed with each refueling operation within each hour varies randomly about some mean value for that day and hour.

Assumption #3 The number obtained by averaging the average hourly gallons dispensed per refueling operation over all hours of all days within the period may be substituted for the individual hourly averages.

Assumption #4 The number of refueling operations per hour is a function of hour of the day but not of the day.

Assumption #5 The hourly average hydrocarbon refueling loss per refueling operation can be expressed as the sum of an hourly average hydrocarbon spill loss and an hourly average displaced hydrocarbon loss.

Assumption #6 The hourly average spill loss per gallon of dispensed fuel varies randomly about a determinable mean value having no relationship to hour of day or day.

Assumption #7 The hourly average displaced hydrocarbon loss can be estimated by a mathematical expression containing the hourly average Reid vapor pressure, the hourly average underground fuel temperature and the hourly average ambient temperature. (This assumption contains within it the assumption that region wide hourly average values of Reid vapor pressure and underground fuel temperature can be used in place of values for each service station within the region.)

Assumption #8 The hourly average underground fuel temperature is constant within any day.

Assumption #9 The hourly average Reid vapor pressure is constant within any day.

Application of Assumptions #1 and #2 to Equation (4-1) allows the summation over n_k to be carried out and the variables L_R and G expressed as hourly averages over all refuelings in a given hour. This operation yields the following general form of the model.

$$L_T = \sum_{j=1}^{D} \sum_{i=1}^{H} R(h_i,d_j)\ \bar{L}_R\ (h_i,d_j)\ \bar{G}\ (h_i,d_j) \qquad (4\text{-}2)$$

where

$\bar{L}_R\ (h_i,d_j)$= The average refueling loss of all refuelings in the h_i-th hour of the d_j-th day in weight per unit volume dispensed.

$\bar{G}\ (h_i,d_j)$ = The volume of dispensed gasoline per refueling operation averaged over all refuelings in the h_i-th hour of the d_j-th day.

$R\ (h_i,d_j)$ = The number of refueling operations in the h_i-th hour of the d_j-th day.

Assumption #3 allows $\overline{G}\ (h_i, d_j)$ to be replaced by $\overline{G}$ and the $\overline{G}$ to be factored out of the summation and placed to the left of the summation signs. Assumption #4 allows $R\ (h_i, d_j)$ to be replaced by $R\ (h_i)$.

Application of the Assumption #3 and the remaining assumptions leads to the desired working model:

$$L'_T = k\overline{G} \sum_{j=1}^{D} \sum_{i=1}^{H} R(h_i)\ [\overline{L}'_S + \overline{L}'_D\ (\overline{T}_U(d_j), \overline{T}_A(h_i, d_j), \overline{P}_V(d_j))] \quad (4\text{-}3)$$

The terms in Equation (4-3) are defined as follows:

L'_T = Estimated total refueling loss for region over specified period in appropriate weight units.

k = Conversion factor from weight unit used in $\overline{L}'_S$ and $\overline{L}'_D$

$\overline{G}$ = Average daily volume of fuel dispensed within the region for the period.

D = Total integral days in specified period.

H = Total integral number of hours refueling operations per day.

$R(h_i)$ = Fraction of total daily refueling operations which occur in h_i-th hour.

$\overline{L}'_S$ = Estimated average spill loss in weight/volume dispensed.

$\overline{L}'_S$ = Estimated hourly average displaced hydrocarbon loss in weight per gallon dispensed.

$\overline{T}_U$ = Regional average underground fuel temperature on a given day, °F.

$\overline{T}_A$ = Regional average ambient temperature for a given hour, °F.

$\overline{P}_V$ = Regional average Reid vapor pressure on a given day, psi.

Note that the $R(h_i)$ and $\overline{G}$ are redefined for convenience (they could have retained their former interpretation).

The second year program has established that:

$$\overline{L}_S = 0.30 \text{ gms/gal} \quad (4\text{-}4)$$

The expression for $\overline{L}'_D$ is derived as follows. From Equation (2-1) of Section 2 and Assumptions #7 - #9 we can write the following analogous approximate expression:

$$\overline{L}'_D = \exp\left(a + b\overline{P}_V\overline{T}_D + d\overline{P}_V + c\overline{T}_T + d\overline{P}_V + e\,\overline{T}_D\overline{T}_T\right) \quad (4\text{-}5)$$

where

$\overline{T}_D$ = Regional average dispensed fuel temperature for a given hour, °F.

$\overline{T}_T$ = Regional average initial tank fuel temperature for a given hour, °F.

The constants a through e are taken as the same as given for Equation (2-1). Note that this is not a precise application of (2-1) since the exponential form and the cross product terms do not permit averaging both sides of the expression in the manner shown (See discussion of Assumption #7 in Section 4.4).

From Equation (3-1) of Section 3:

$$\overline{T}_D = f + g\,\overline{T}_U + h\,\overline{T}_A \quad (4\text{-}6)$$

Where the constants f, g, and h are the same as for Equation (3-1). Because of the linearity of Equation (3-1) there is no difficulty taking averages on both sides of the equation.

The Coordinating Research Council APRAC Program on fuel system temperatures, CAPE-5, showed that the fuel tank temperature of an operating vehicle could vary up to 25° above ambient (Reference 7). The following simple relationship is used here:

$$\overline{T}_T = \overline{T}_A + \Delta T \quad (4\text{-}7)$$

If Equations (4-6) and (4-7) are substituted into (4-5) the following expression is obtained:

$$\overline{L}'_D(h_i,d_j) = \exp(C_1 + C_2\overline{P}_V(d_j) + C_3\overline{T}_A(h_i,d_j) + C_4\overline{T}_U(d_j) + C_5\overline{P}_V(d_j)\overline{T}_A(h_i,d_j) + C_6\overline{P}_V(d_j)\overline{T}_U(d_j) + C_7\overline{T}_A(h_i,d_j)\overline{T}_U + C_8\overline{T}_A^2(h_i,d_j)) \quad (4\text{-}8)$$

where

$$C_1 = a + c\,T + ef\,\Delta T$$
$$C_2 = bf + d$$
$$C_3 = c + ef + eh\,\Delta T \qquad (4\text{-}9)$$
$$C_4 = eg\,\Delta T$$
$$C_5 = bh$$
$$C_6 = bg$$
$$C_7 = eg$$
$$C_8 = eh$$

Substituting the appropriate values of the constants from Equations (2-1) and (3-1) and the value of 7.0 for ΔT. (See discussion of Assumption #11 in Section 4.4).

$$C_1 = -1.0141 \times 10^{-1}$$
$$C_2 = 5.2740 \times 10^{-2}$$
$$C_3 = -1.2164 \times 10^{-3}$$
$$C_4 = 6.0649 \times 10^{-4} \qquad (4\text{-}10)$$
$$C_5 = 2.6115 \times 10^{-4}$$
$$C_6 = 9.3072 \times 10^{-4}$$
$$C_7 = 8.6642 \times 10^{-5}$$
$$C_8 = 2.4310 \times 10^{-5}$$

In deriving Equations (4-4) and (4-8) the following additional assumptions were made.

Assumption #10 The average spill loss per gallon of fuel dispensed is 0.30 gms.

Assumption #11 Equations (2-1), (3-1) and (4-7) provide a reasonable basis for defining $\overline{L}_D'$

Equations (4-3), (4-4), (4-8) and (4-10) constitute the model along with the frequency distribution of refuelings given in Table 3-5. The model is summarized in Table 4-1.

4.2 Computer Program of the Regional Model

The regional model applied to a thirty-one day period would require the calculation of 31 x 16 = 496 values of the moderately complex expression $L'_D(h_i d_j)$ which is itself the exponential of an eight term polynomial. Thus any extensive use of the model would be greatly aided by use of a computer. Accordingly, a computer program of the model was constructed and is listed in Appendix F. The program allows up to 99 cases to be run in a single batch operation. Each case may apply to a different region and cover any specified time period up to 400 days.

The program also has three options which are to be specified: Option 1 allows printing the coefficients of the model's displaced hydrocarbon loss equation; Option 2 allows a single data card to be used to cover the period under study rather than a data card for each day if the gallons of fuel dispensed per day, the Reid vapor pressure, and the underground fuel temperature are constant over the period; and Option 3 allows printing out the input data. Option 2 implies a slight departure from the model presented in Table 4-1. The computer program allows a different value of gallons dispensed to be used for each day while the model uses only an average value for the period.

Another feature of the program is that new, improved values for the basic regression coefficients derived in Section 3, as well as $\triangle T$ and the average spill loss can be easily inserted without altering other program steps. This is possible because the coefficients of the displaced loss equation of the model, Equation (4-8), are calculated by the computer from the base regression coefficients and $\triangle T$ each time a batch of cases is run. The data for the base coefficients, $\triangle T$, and the average spill loss are contained on individual data cards in the program deck (See steps 11 through 16 of the program listed in Appendix F).

Table 4-1 Regional Model for Hydrocarbon Refueling Losses

$$L'_T = \frac{\bar{G}}{453.6} \sum_{j=1}^{D} \sum_{i=1}^{H} R(h_i)\,(\bar{L}'_S + \bar{L}'_D\,(h_i,d_j))$$

$$\bar{L}'_S = 0.30$$

$$\bar{L}'_D(h_i,d_j) = \mathrm{Exp}(C_1 + C_2\bar{P}_V(d_j) + C_3\bar{T}_A(h_i,d_j) + C_4\bar{T}_U(d_j) + C_5\bar{P}_V(d_j)\,\bar{T}_A(h_i,d_j) + C_6\bar{P}_V(d_j)\bar{T}_U(d_j) + C_7\bar{T}_A(h_i,d_j)\bar{T}_U + C_8\bar{T}_A^{\,2}\,(h_i,d_j))$$

C_1	-1.0141×10^{-1}	C_5	2.6115×10^{-4}
C_2	5.2740×10^{-2}	C_6	9.3072×10^{-4}
C_3	-1.2164×10^{-3}	C_7	8.6642×10^{-5}
C_4	6.0649×10^{-4}	C_8	2.4310×10^{-5}

where

L'_T = Estimated total hydrocarbon refueling loss for region over D days, pounds.

$\bar{L}'_S$ = Estimated average spill loss, gms/gal dispensed.

$\bar{L}'_D$ = Estimated average displaced hydrocarbon loss, gms/gal dispensed.

$\bar{G}$ = Average daily volume of fuel dispensed within the region for the period, gallons.

D = Total integral days in specified period.

H = Total integral number of hours of refueling operations per day (fixed for period).

$R(h_i)$ = Fraction of total daily refueling operations which occur in h_i-th hour.

$\bar{T}_U$ = Regional average underground fuel temperature on a given day, °F.

$\bar{T}_A$ = Regional average ambient temperature for a given hour, °F.

$\bar{P}_V$ = Regional average Reid vapor pressure on a given day, psi.

The input information required to operate the program is as follows:

- o Number of cases to be run.
- o Option 1 selection:
  - Option 1 = 0 Will not print loss equation coefficients.
  - Option 1 = 1 Will print loss equation coefficients.
- o For each case:
  - The number of days to be covered.
  - Option 2 and 3 selections:
    - Option 2 = 0 Gallons dispensed per day, Reid vapor pressure, underground fuel temperature are constant over the days to be covered.
    - Option 2 = 1 Above variables change over the days to be covered.
    - Option 3 = 0 Will not print input data.
    - Option 3 = 1 Will print input data.
  - $G(d_j)$, gallons of fuel dispensed in the region for each day of the period.
  - $\overline{T}_U(d_j)$, regional average underground fuel temperature for each day, °F.
  - $\overline{P}_V(d_j)$, regional average Reid vapor pressure for each day, psi.
  - $\overline{T}_A(h_i d_j)$, regional average ambient temperature for each hour of each day, °F.

The ordering and layout of the data input cards is given in Table 4-2. It is seen that the first card indicates the number of cases to be run and the Option 1 choice. The data cards are then grouped by case. Each case begins with a card indicating the number of days for that case and the choices regarding Options 2 and 3. The data cards follow. Although each data card is referenced by the day, it is important that the cards be ordered by day as indicated in Table 4-2. The program tests for correct ordering. If the cards are not in sequence further execution of the program will be stopped. In this case both an error message and the data card which is out of place are printed.

As an illustration of the use of the program, the input and output for a two case calculation is given here. The first case is for a period of 31 days during the summer months while the second case covers 31 days during

Table 4-2 Preparation and Ordering of Input Cards For Regional Model Computer Program

Card Number	Format	Information Entered	Column Numbers
1	3X, I2, 4X, I1	o Number of refueling loss cases to be run	4-5
		o Choice of Option 1	10
		* * * * * Case 1 * * * * *	
2	2X, I3, 2(4X, I1)	o Number of days in Case 1	3-5
		o Choice of Option 2	10
		o Choice of Option 3	15
3	I5, 5X, F10.0, 2(5X, F5.0)	o Day one	1-5
		o G (1), total gallons dispensed first day	11-20
		o $\overline{P}_V$ (1), average regional Reid vapor pressure, (psi) for first day	26-30
		o $\overline{T}_U$ (1), average underground fuel temperature, (°F), for region on first day	36-40
4-31	Assumes 31 days in Case 1. Same format and variables as Card 3 but for each succeeding day up to and including last day of case. Note: If Option 2 = 0 only one card needed for these variables and columns 1-5 may be left blank.		
32	15, 1X, 16 F4.0	o Day one	1-5
		o T_A (1,1) average regional temperature, °F, for first hour of first day	7-10
		.	.
		.	.
		.	.
		o T_A (16,1) average ambient temperature, °F, for 16th hour of first day.	67-70
33-62	Same format Card 32 and same variables but for each succeeding day up to last day of case.		
		* * * * * Case 2, 3, etc. * * * * *	
	Same set up as shown for Case 1. Load card groups for each case successively.		

the winter months. For comparison purposes the number of gallons dispensed was held constant in both cases at one million gallons per day. For the summer case it was assumed that the daily average underground fuel temperature remained constant at 76°F for the summer period and 30°F for the winter period. It was also assumed that the average RVP of the fuels was constant at 7.5 psi for the summer cases and 12.0 psi for the winter cases.

The ambient temperatures for the summer months were obtained from the Weather Service. However, the temperatures obtained exceeded ninety degrees and thus were beyond the validity range of the displaced HC loss expression. In fact, because of the addition of the ΔT term, the ambient temperature cannot exceed (90°F - ΔT) without going beyond the range of the model. Consequently, to obtain a set of temperature data for the illustration each ambient temperature was reduced by 10°F. The adjusted ambient temperatures for the summer case are shown in Table 4-5. The winter ambient temperature data were obtained in Minneapolis during the month of January. Since only 14 days of data were obtained they were replicated to yield 31 days of winter data as shown in Table 4-8.

Since it was desired to show the calculated displaced HC loss equation, Option 1 was set to one. Because gallons dispensed per day, Reid vapor pressure, and underground fuel temperature were chosen to be constant within each of the 31 day periods, Option 2 was set at zero (or left undesignated on the card). It was also desired to printout all the input data for each case and, therefore, Option 3 was set at one.

The ordering of the data in the input data cards is illustrated in Table 4-3 and follows the procedure given set forth in Table 4-2.

The program outputs are shown in the next seven tables. Table 4-4 shows the eight computed coefficients of the expression for average displaced hydrocarbon loss (See Equation (4-10)). Table 4-5 shows the input data for the summer case. The calculated hydrocarbon losses are given in the next two tables. The first, Table 4-6 gives the hydrocarbon refueling losses in pounds for each day of the summer period together with the total period loss and the average loss in grams/gallon dispensed. The second, Table 4-7 shows the loss for each hour from 0600 to 2200 hours summed over the total number of days in the period. Input data for the winter case is given in Tables 4-8. The refueling losses for the winter are shown in Tables 4-9 and 4-10.

The average loss of 5.08 gms/gal for the summer case is high but within the valid range of the model. It is noted that the daily losses for both cases do not exhibit large fluctuations. The larger fluctuations in the case of the hourly losses is partly due to influence of the hourly refueling frequencies.

Table 4-3 Sample Input Data Cards for Computer Program of Regional Model

"C" FOR COMMENT

	STATEMENT NUMBER (5)	CONT. (6)	FORTRAN STATEMENT (7 10 20 30 40)
1	2		1
2	31		0 1
3			1.000.000 7.5 76
4	1		65 71 75 76 78 81 81 81
5	2		66 73 74 77 78 80 81 81
6	3		68 73 74 76 71 72 68 67
7	4		66 69 71 75 77 77 75 74
			etc through card 34
35	31		0 1
36			1.000.000 12.0 30
37	1		0 1 1 1 2 4 8 10
38	2		16 16 17 17 17 17 17 18
39	3		17 17 19 23 24 23 27 28
40	4		17 17 19 23 24 23 27 28
			etc through card 67

Table 4-4 Computer Listing of Coefficients to Displaced Hydrocarbon Loss Equation of Regional Model

THE CALCULATED COEFFICIENTS ARE:

C(1) = -.10141+00

C(2) = .52740-01

C(3) = -.12164-02

C(4) = .60649-04

C(5) = .26115-05

C(6) = .95072-05

C(7) = .88642-04

C(8) = .24510-04

Table 4-5 Computer Listing of Input Data for Summer Month Calculation

* * * * * INPUT DATA * * * * *

AY	FUEL DISPENSED (GAL/DAY)	RVP (PSIA)	UNDERGRD FUEL TEMP. (DEG F)	AMBIENT TEMPERATURE, DEG F 0600 TO 0700	0700 TO 0800	0800 TO 0900	0900 TO 1000	1000 TO 1100	1100 TO 1200	1200 TO 1300	1300 TO 1400	1400 TO 1500	1500 TO 1600	1600 TO 1700	1700 TO 1800	1800 TO 1900	1900 TO 2000	2000 TO 2100	2100 TO 2200
1	1.000+06	7.5	70.	65.	71.	75.	76.	78.	81.	81.	81.	83.	81.	80.	77.	77.	75.	70.	69.
2	1.000+06	7.5	70.	66.	73.	74.	77.	78.	80.	81.	81.	80.	83.	79.	79.	76.	74.	72.	69.
3	1.000+06	7.5	70.	68.	73.	74.	76.	71.	72.	68.	67.	69.	72.	75.	75.	75.	71.	68.	68.
4	1.000+06	7.5	70.	66.	69.	71.	73.	77.	77.	75.	74.	76.	75.	75.	74.	74.	75.	70.	70.
5	1.000+06	7.5	70.	66.	71.	75.	75.	79.	78.	80.	79.	80.	80.	80.	78.	78.	74.	71.	69.
6	1.000+06	7.5	70.	68.	73.	75.	78.	79.	79.	79.	81.	81.	79.	79.	78.	75.	75.	71.	69.
7	1.000+06	7.5	70.	66.	72.	76.	78.	79.	80.	81.	82.	81.	80.	79.	79.	75.	75.	71.	69.
8	1.000+06	7.5	70.	66.	72.	74.	78.	78.	78.	81.	78.	80.	80.	79.	79.	77.	74.	71.	70.
9	1.000+06	7.5	70.	67.	71.	74.	76.	78.	80.	81.	81.	80.	80.	79.	77.	76.	74.	72.	71.
10	1.000+06	7.5	70.	66.	70.	73.	76.	78.	81.	80.	82.	83.	82.	82.	81.	79.	75.	74.	72.
11	1.000+06	7.5	70.	67.	70.	73.	75.	79.	80.	81.	83.	83.	82.	82.	82.	82.	70.	66.	66.
12	1.000+06	7.5	70.	66.	70.	73.	75.	79.	81.	82.	83.	83.	82.	80.	81.	71.	69.	70.	69.
13	1.000+06	7.5	70.	67.	70.	71.	72.	74.	78.	78.	79.	80.	80.	69.	70.	69.	70.	69.	67.
14	1.000+06	7.5	70.	69.	72.	72.	73.	75.	78.	78.	79.	73.	75.	76.	76.	75.	74.	72.	71.
15	1.000+06	7.5	70.	69.	70.	71.	74.	75.	75.	75.	72.	74.	72.	74.	75.	74.	72.	70.	69.
16	1.000+06	7.5	70.	65.	72.	73.	77.	78.	74.	73.	73.	73.	75.	76.	76.	76.	72.	70.	70.
17	1.000+06	7.5	70.	67.	71.	73.	75.	77.	80.	81.	83.	79.	80.	78.	76.	75.	75.	71.	70.
18	1.000+06	7.5	70.	67.	71.	74.	75.	77.	75.	69.	73.	78.	75.	77.	76.	75.	72.	69.	69.
19	1.000+06	7.5	70.	67.	70.	73.	73.	76.	75.	76.	75.	70.	66.	67.	67.	70.	69.	66.	66.
20	1.000+06	7.5	70.	64.	68.	70.	72.	73.	75.	76.	76.	78.	79.	78.	78.	78.	76.	74.	71.	70.
21	1.000+06	7.5	70.	65.	69.	72.	74.	77.	77.	81.	80.	82.	80.	82.	80.	79.	78.	74.	72.	70.
22	1.000+06	7.5	70.	66.	67.	71.	73.	75.	76.	80.	81.	81.	83.	77.	69.	68.	69.	69.	68.	67.
23	1.000+06	7.5	70.	68.	68.	71.	72.	74.	76.	72.	69.	68.	70.	72.	71.	71.	70.	68.	67.
24	1.000+06	7.5	70.	66.	70.	73.	75.	77.	78.	75.	78.	74.	77.	78.	78.	75.	75.	70.	69.
25	1.000+06	7.5	70.	67.	75.	75.	77.	79.	80.	81.	83.	80.	77.	80.	77.	77.	74.	71.	70.
26	1.000+06	7.5	70.	67.	72.	72.	76.	79.	78.	82.	80.	80.	79.	79.	79.	77.	75.	72.	71.
27	1.000+06	7.5	70.	67.	75.	72.	77.	79.	81.	81.	79.	77.	79.	80.	78.	77.	74.	75.	71.
28	1.000+06	7.5	70.	66.	66.	68.	69.	73.	74.	76.	75.	76.	79.	78.	76.	74.	72.	70.	69.
29	1.000+06	7.5	70.	65.	69.	72.	75.	76.	80.	81.	82.	83.	77.	80.	79.	79.	75.	71.	69.
30	1.000+06	7.5	70.	64.	68.	72.	75.	78.	78.	80.	80.	80.	83.	82.	81.	80.	77.	75.	75.
31	1.000+06	7.5	70.	68.	70.	72.	75.	79.	80.	80.	81.	77.	76.	77.	74.	74.	73.	72.	72.

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Table 4-6 Summer Month Refueling Losses by Day

SUMMARY OF LOSSES BY DAY, IN POUNDS OF HYDROCARBONS

DAY	1	LOSS =	11407.
DAY	2	LOSS =	11424.
DAY	3	LOSS =	10701.
DAY	4	LOSS =	11091.
DAY	5	LOSS =	11550.
DAY	6	LOSS =	11500.
DAY	7	LOSS =	11407.
DAY	8	LOSS =	11361.
DAY	9	LOSS =	11567.
DAY	10	LOSS =	11557.
DAY	11	LOSS =	11495.
DAY	12	LOSS =	11586.
DAY	13	LOSS =	10940.
DAY	14	LOSS =	11122.
DAY	15	LOSS =	10847.
DAY	16	LOSS =	11024.
DAY	17	LOSS =	11509.
DAY	18	LOSS =	11094.
DAY	19	LOSS =	10969.
DAY	20	LOSS =	11127.
DAY	21	LOSS =	11410.
DAY	22	LOSS =	10987.
DAY	23	LOSS =	10951.
DAY	24	LOSS =	11120.
DAY	25	LOSS =	11505.
DAY	26	LOSS =	11582.
DAY	27	LOSS =	11571.
DAY	28	LOSS =	10994.
DAY	29	LOSS =	11575.
DAY	30	LOSS =	11459.
DAY	31	LOSS =	11210.

THE TOTAL LOSS OVER THE 31-DAY PERIOD = 347297.

THE AVERAGE LOSS = 5.08 LB/GAL

Table 4-7 Summer Month Refueling Losses by Hour Summed over Month

SUMMARY OF LOSSES BY HOURS IN POUNDS OF HYDROCARBONS

HOUR	1	LOSS =	5567.
HOUR	2	LOSS =	14521.
HOUR	3	LOSS =	14969.
HOUR	4	LOSS =	20229.
HOUR	5	LOSS =	21259.
HOUR	6	LOSS =	24961.
HOUR	7	LOSS =	23504.
HOUR	8	LOSS =	24945.
HOUR	9	LOSS =	26937.
HOUR	10	LOSS =	27375.
HOUR	11	LOSS =	27049.
HOUR	12	LOSS =	29261.
HOUR	13	LOSS =	29261.
HOUR	14	LOSS =	25115.
HOUR	15	LOSS =	18119.
HOUR	16	LOSS =	11406.

Table 4-8 Computer Listing of Input Data for Winter Month

* * * * * INPUT DATA * * * * *

DAY	FUEL DISPENSED (GAL/DAY)	RVP (PSIA)	UNDERGND FUEL TEMP. (DEG F)	AMBIENT TEMPERATURE, DEG F 0600 TO 0700	0700 TO 0800	0800 TO 0900	0900 TO 1000	1000 TO 1100	1100 TO 1200	1200 TO 1300	1300 TO 1400	1400 TO 1500	1500 TO 1600	1600 TO 1700	1700 TO 1800	1800 TO 1900	1900 TO 2000	2000 TO 2100	2100 TO 2200
1	1.000+06	12.0	50.	0.	1.	1.	1.	2.	4.	8.	10.	11.	12.	12.	9.	8.	6.	5.	4.
2	1.000+06	12.0	50.	16.	16.	17.	17.	17.	17.	17.	18.	18.	18.	18.	17.	17.	17.	17.	19.
3	1.000+06	12.0	50.	17.	17.	19.	23.	24.	23.	21.	26.	27.	27.	27.	24.	22.	19.	18.	15.
4	1.000+06	12.0	50.	17.	17.	19.	23.	24.	23.	21.	26.	27.	27.	27.	24.	22.	19.	18.	15.
5	1.000+06	12.0	50.	20.	22.	23.	26.	28.	35.	36.	38.	40.	40.	39.	38.	37.	37.	37.	36.
6	1.000+06	12.0	50.	32.	33.	33.	34.	35.	34.	34.	34.	33.	33.	33.	32.	32.	32.	32.	32.
7	1.000+06	12.0	50.	37.	37.	37.	39.	42.	44.	44.	45.	42.	42.	40.	38.	37.	36.	35.	34.
8	1.000+06	12.0	50.	34.	34.	34.	34.	35.	35.	36.	38.	39.	41.	39.	39.	39.	39.	39.	39.
9	1.000+06	12.0	50.	16.	17.	17.	15.	14.	20.	21.	22.	23.	23.	23.	23.	23.	22.	22.	22.
10	1.000+06	12.0	50.	23.	24.	24.	24.	25.	26.	28.	28.	29.	28.	28.	28.	28.	28.	28.	28.
11	1.000+06	12.0	50.	25.	25.	25.	25.	28.	29.	28.	28.	28.	28.	28.	28.	27.	27.	26.	25.
12	1.000+06	12.0	50.	9.	9.	10.	11.	14.	18.	21.	24.	25.	25.	25.	27.	25.	22.	20.	18.
13	1.000+06	12.0	50.	20.	20.	20.	23.	30.	34.	35.	35.	38.	39.	38.	35.	33.	32.	32.	31.
14	1.000+06	12.0	50.	28.	28.	28.	32.	37.	39.	41.	45.	48.	47.	44.	40.	37.	35.	33.	32.
15	1.000+06	12.0	50.	28.	28.	27.	32.	36.	39.	42.	44.	45.	44.	42.	41.	38.	34.	30.	27.
16	1.000+06	12.0	50.	0.	1.	1.	1.	2.	4.	8.	10.	11.	12.	12.	9.	8.	6.	5.	4.
17	1.000+06	12.0	50.	16.	16.	17.	17.	17.	17.	17.	18.	18.	18.	18.	17.	17.	17.	17.	19.
18	1.000+06	12.0	50.	20.	22.	23.	26.	28.	35.	36.	38.	40.	40.	39.	38.	37.	37.	37.	36.
19	1.000+06	12.0	50.	32.	33.	33.	34.	35.	34.	34.	34.	33.	33.	33.	32.	32.	32.	32.	32.
20	1.000+06	12.0	50.	37.	37.	37.	39.	42.	44.	44.	45.	42.	42.	40.	38.	37.	36.	35.	34.
21	1.000+06	12.0	50.	34.	34.	34.	34.	35.	35.	36.	38.	39.	41.	39.	39.	39.	39.	39.	39.
22	1.000+06	12.0	50.	16.	17.	17.	15.	14.	20.	21.	22.	23.	23.	23.	23.	23.	22.	22.	22.
23	1.000+06	12.0	50.	23.	24.	24.	24.	25.	26.	28.	28.	29.	28.	28.	28.	28.	28.	28.	28.
24	1.000+06	12.0	50.	25.	25.	25.	25.	28.	29.	28.	28.	28.	28.	28.	28.	27.	27.	26.	25.
25	1.000+06	12.0	50.	9.	9.	10.	11.	14.	18.	21.	24.	25.	25.	25.	27.	25.	22.	20.	18.
26	1.000+06	12.0	50.	20.	20.	20.	23.	30.	34.	35.	35.	38.	39.	38.	35.	33.	32.	32.	31.
27	1.000+06	12.0	50.	28.	28.	28.	32.	37.	39.	41.	45.	48.	47.	44.	40.	37.	35.	33.	32.
28	1.000+06	12.0	50.	28.	28.	27.	32.	36.	39.	42.	44.	45.	44.	42.	41.	38.	34.	30.	27.
29	1.000+06	12.0	50.	0.	1.	1.	1.	2.	4.	8.	10.	11.	12.	12.	9.	8.	6.	5.	4.
30	1.000+06	12.0	50.	16.	16.	17.	17.	17.	17.	17.	18.	18.	18.	18.	17.	17.	17.	17.	19.
31	1.000+06	12.0	50.	17.	17.	19.	23.	24.	23.	21.	26.	27.	27.	27.	24.	22.	19.	18.	15.

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Table 4-9 Winter Month Refueling Losses by Day

SUMMARY OF LOSSES BY DAY, IN POUNDS OF HYDROCARBONS

DAY	1	LOSS =	6177.
DAY	2	LOSS =	6478.
DAY	3	LOSS =	6673.
DAY	4	LOSS =	6673.
DAY	5	LOSS =	7104.
DAY	6	LOSS =	7026.
DAY	7	LOSS =	7294.
DAY	8	LOSS =	7210.
DAY	9	LOSS =	6605.
DAY	10	LOSS =	6606.
DAY	11	LOSS =	6612.
DAY	12	LOSS =	6582.
DAY	13	LOSS =	7015.
DAY	14	LOSS =	7257.
DAY	15	LOSS =	7222.
DAY	16	LOSS =	6177.
DAY	17	LOSS =	6478.
DAY	18	LOSS =	7104.
DAY	19	LOSS =	7026.
DAY	20	LOSS =	7294.
DAY	21	LOSS =	7210.
DAY	22	LOSS =	6605.
DAY	23	LOSS =	6606.
DAY	24	LOSS =	6612.
DAY	25	LOSS =	6582.
DAY	26	LOSS =	7015.
DAY	27	LOSS =	7257.
DAY	28	LOSS =	7222.
DAY	29	LOSS =	6177.
DAY	30	LOSS =	6478.
DAY	31	LOSS =	6673.

THE TOTAL LOSS OVER THE 31-DAY PERIOD = 211864.

THE AVERAGE LOSS = 3.10 GMS/GAL

Table 4-10 Winter Month Refueling Losses by Hour Summed Over Month

SUMMARY OF LOSSES BY HOUR, IN POUNDS OF HYDROCARBONS

HOUR	1	LOSS =	5556.
HOUR	2	LOSS =	8927.
HOUR	3	LOSS =	9147.
HOUR	4	LOSS =	12156.
HOUR	5	LOSS =	12704.
HOUR	6	LOSS =	14629.
HOUR	7	LOSS =	15271.
HOUR	8	LOSS =	14944.
HOUR	9	LOSS =	16500.
HOUR	10	LOSS =	16650.
HOUR	11	LOSS =	16455.
HOUR	12	LOSS =	17024.
HOUR	13	LOSS =	17915.
HOUR	14	LOSS =	16555.
HOUR	15	LOSS =	11541.
HOUR	16	LOSS =	7515.

Section 4.3 Simplified Forms of the Regional Model

As indicated in the last section the Regional model involves a large enough number of calculations to make the use of a computer very desirable. In deriving the model it was necessary to sacrifice some accuracy through the use of averages. If this process is carried further the model can be simplified to the point that the use of electronic calculators becomes practical. The first simplification that can be made is to use regional hourly average ambient temperature averaged over the days of the period and regional average values of $\bar{T}_U(d_j)$ and $\bar{P}_V(d_j)$ over the period.

Thus:

$$\bar{\bar{T}}_A(h_i) = \frac{1}{D} \sum_{j=1}^{D} \bar{T}_A(h_i, d_j) \quad i = 1,2, \cdots\cdots ,16 \tag{4-11}$$

$$\bar{\bar{T}}_U = \frac{1}{D} \sum_{j=1}^{D} \bar{T}_U(d_j) \tag{4-12}$$

$$\bar{\bar{P}}_V = \frac{1}{D} \sum_{j=1}^{D} \bar{P}_v(d_j) \tag{4-13}$$

In this case the model becomes

$$L''_T = \frac{\bar{G}D}{453.6} \sum_{i=1}^{H} R(h_i) \left[\bar{L}'_S + \bar{L}''_D \left(\bar{\bar{P}}_V, \bar{\bar{T}}_U, \bar{\bar{T}}_A(h_i)\right)\right] \tag{4-14}$$

A final simplification can be made by employing the average of the hourly average ambient temperatures

$$\bar{\bar{\bar{T}}}_A = \frac{1}{H} \sum_{i=1}^{H} \bar{\bar{T}}_A(h_j) \tag{4-15}$$

to give:

$$L'''_T = \frac{\bar{G}D}{453.6} \left[L'_S + \bar{L}'''_D \left(\bar{\bar{P}}_V, \bar{\bar{T}}_U, \bar{\bar{\bar{T}}}_A\right)\right] \tag{4-16}$$

The additional primes on the total loss in Equations (4-14) and (4-16) are to emphasize that these are, in effect, estimates of previous estimates. Each additional substitution of an average further reduces the accuracy of the estimate.

It should be noted that $\overline{\overline{T}}_A$ may be obtained by applying (4-11) and then (4-15) or (4-15) followed by (4-11). Both give the same result. Thus $\overline{\overline{T}}_A$ may be interpreted as the average over the period of the daily average temperature (for the 16 hour period).

If the period covered by the calculation is no more than a month, the use of (4-14) will lead to only slightly increased error. The Reid vapor pressures of the gasolines supplied to an area will not vary by much in the period of a month. Underground fuel temperatures would be expected to vary only a few degrees. The ambient temperature will show the greatest variation from day to day. But the variation will be predominantly random within a month period, and Equation (4-14) accounts for the more systematic diurnal variation in ambient temperature. Detailed sample calculations, employing Equations (4-14) and (4-16) for the winter and summer condition examples treated in the last section are given in the following paragraphs:

In the summer case it was assumed for the 31 day period that $\overline{G}$ = 1,000,000 gals/d, $\overline{\overline{P}}_V$ = 7.5 psi, and $\overline{\overline{T}}_U$ = 76°F. The hourly average summer month temperatures calculated from Table 4-3 are given in Table 4-11 along with their standard deviations.

The agreement between the computer runs and the Equation (4-16) calculations for the fully averaged case is not as good, but even here results only differ by 1% which is less than the error in the displaced loss equations.

The loss calculated by Equation (4-16) would be expected to tend somewhat below the result calculated by the more precise methods since the exponential equation would give greater weight to temperatures higher than the mean temperature.

It can be concluded that Equations (4-14) and (4-16) are useful calculations in estimating regional losses

Table 4-11 Average Ambient Temperatures for Thirty One Day Periods Summer and Winter

Hour Beginning:	Summer Period		Winter Period	
	Average Temperature °F	Standard Deviation °F	Average Temperature °F	Standard Deviation °F
0600	66.5	1.3	21.2	10.3
0700	70.4	1.9	21.0	10.0
0800	72.6	1.6	21.4	9.8
0900	75.3	2.0	23.4	10.4
1000	77.0	2.2	25.4	11.1
1100	78.2	2.5	27.0	11.3
1200	78.2	3.9	28.7	10.7
1300	78.7	4.1	29.9	10.6
1400	78.2	4.2	30.6	10.9
1500	77.8	4.0	30.7	10.7
1600	77.3	3.9	30.0	9.9
1700	76.6	3.5	26.6	9.9
1800	75.4	3.1	27.4	9.6
1900	72.7	2.0	26.3	9.8
2000	70.5	2.0	25.4	9.8
2100	69.5	1.6	24.6	9.9
Grand Average	74.7	3.8(1)	26.2	3.3(1)

(1) Standard deviation of the hourly averages from the Grand Average

Applying Equation 4-16 first to show the relative value of the terms in the exponential expression for L_T''' we have for the L_T''' exponent polynomial.

C_1	= -0.10141		= -0.10141
C_2P_V	= 5.274 [illegible] x 7.5		= 0.39555
$C_3\bar{\bar{T}}_A$	= -1.216[illegible] 10^{-3} x 74.7		= -0.09086
$C_4\bar{\bar{T}}_U$	= 6.0649×10^{-4} x 67		= 0.04609
$C_5\bar{\bar{P}}_V\bar{\bar{T}}_A$	= 2.6115×10^{-4} x 7.5 x 74.7		= 0.14631
$C_6\bar{\bar{P}}_V\bar{\bar{T}}_U$	= 9.3072×10^{-4} x 7.5 x 67		= 0.53051
$C_7\bar{\bar{T}}_A\bar{\bar{T}}_U$	= 8.6642×10^{-5} x 74.7 x 67		= 0.49188
$C_8\bar{\bar{T}}_A^2$	= 2.4310×10^{-5} x $(74.7)^2$		= 0.13565
			1.55372

L_D''' = exp. 1.55372 = 4.73 gms/gal

$L_S' + L_D'''$ = 0.30 + 4.73 = 5.03 gms/gal

L_T''' = $\frac{1{,}000{,}000}{453.6}$ x 31 x 5.03 = 344,000 lbs in 31 days

Carrying through the calculation with Equation (4-14) yields:

Hour Index	Hour Beginning	Loss, gms/gal Displaced	Loss, gms/gal Total	$R(h_i)$	Loss x R (gms/gal)	31 Days* Hourly Loss (lbs)
1	0600	4.330	4.630	0.0175	0.0810	5536
2	0700	4.513	4.818	0.0435	0.2094	14311
3	0800	4.622	4.922	0.0445	0.2190	14967
4	0900	4.760	5.060	0.0585	0.2960	20229
5	1000	4.850	5.150	0.0605	0.3116	21295
6	1100	4.915	5.215	0.0700	0.3651	24952
7	1200	4.915	5.215	0.0715	0.3729	25485
8	1300	4.943	5.243	0.0695	0.3644	24903
9	1400	4.915	5.215	0.0755	0.3938	26913
10	1500	4.894	5.194	0.0770	0.3999	27330
11	1600	4.867	5.167	0.0765	0.3952	27009
12	1700	4.829	5.129	0.0835	0.4283	29271
13	1800	4.766	5.066	0.0845	0.4280	29250
14	1900	4.627	4.927	0.0775	0.3818	26093
15	2000	4.518	4.818	0.0550	0.2650	18111
16	2100	4.470	4.770	0.0350	0.1670	11413
					5.0784	347069

$$* \; [\text{Loss} \times R(h_i)] \times 31 \times \frac{1{,}000{,}000}{435.6}$$

The same calculation can be performed for the winter case starting with the averaged ambient temperatures shown in Table 4-10. The results of both the summer and winter calculation are summarized in Table 4-12 which compares them with the computer results shown in the last section. It is seen that Equation (4-14) agrees within one percent of the results calculated by computer employing the full model. This result would have been suspected for the summer case since as indicated by the low standard deviations in Table 4-2 the temperature profiles do not disagree much from day to day. However, they disagree substantially more in the winter case and the agreement is still excellent.

Table 4-12 Comparison of Results From Computer Run and Short Calculations

Hour Index	Summer Month Total Loss, lbs/31 days		Winter Month Total Loss, lbs/31 days	
	Computer	Eq. 4-14	Computer	Eq. 4-14
1	5537	5536	3586	3588
2	14321	14311	8927	8895
3	14969	14967	9147	9118
4	20229	20229	12152	12107
5	21289	21295	12704	12651
6	24961	24952	14829	14767
7	25504	25485	15271	15213
8	24945	24903	14942	14884
9	26937	26913	16300	16230
10	27375	27330	16630	16562
11	27049	27009	16453	16391
12	29281	29271	17824	17781
13	29261	29250	17913	17856
14	26115	26093	16333	16282
15	18119	18111	11541	11501
16	11406	11413	7313	7289
	347297	347069	211864	211109

	Average Refueling Loss - Grams/Gal.	
	Summer	Winter
Computer	5.08	3.10
Eq. 4-14	5.08	3.09
Eq. 4-16	5.03	3.07

Section 4.4 Error and Sensitivity Analysis of the Regional Model

This section examines the basis of the regional model so that its utility and limitations may be appreciated by the potential user. The analysis will examine each of the underlying assumptions and how they affect the accuracy and applicability of the model.

Assumption #1 The loss L_R for a given refueling operation is not a function of fuel dispensed:

This assumption was used to set the basis for maintaining the separation of the fuel dispensed variable, G, from the loss variable, L_R, in Equation (4-2) and those that follow. Thus, the total loss, $L_R G$, is then directly proportional to the volume of fuel dispensed per operation. The second year program showed good proportionately between measured displaced HC losses and gallons dispensed when the dispensed fuel and fuel tank temperatures were the same. However, further analysis leads to the conclusion that the assumption is not strictly correct (Reference 8) for those conditions in which there is a temperature difference between the dispensed fuel and the vehicle tank fuel. It is correct, however, even with temperature differences, both for very small amounts of dispensed fuel and complete filling of the tank. Calculations show that the dependence of L_R on volume of fuel dispensed may be as much as 10 percent in an individual refueling where the tank is only partially filled.

The displaced loss equation derived in Section 2 was based on partial fillings. Ten gallons of fuel were added to a 22 gallon tank containing 4 gallons of fuel. Thus the vapor volume above the original fuel level was only 56% depleted. The effect of dispensed fuel volume was probably near maximum in this case, so that the resulting displaced loss expression tends to be in error for cases of complete refuelings or the addition of only small amounts of fuel when a temperature difference exists. Since the third year field survey showed the tank was filled in about two thirds of the refueling operations observed, there may be some bias in the displaced loss portion of the model. Its magnitude is difficult to judge without more experimental data. It will be reduced by the averaging process of the model since the effect can both increase or decrease losses depending upon whether the incoming fuel is hotter or colder than the vehicle tank fuel. The average error is estimated to be $\pm$ 3%.

Part of the Loss, L_R, is made up of spill loss which is very unlikely to be related to amount of fuel dispensed. So long as average gallons dispensed per refueling does not vary substantially from region to region or period to period within a region, that is so long as gallons dispensed is a good general index of number of refuelings, no significant error results from this approach. As pointed out in Section 3.3 the mean number of gallons dispensed was 10.4 gallons in the third year program and 11.4 gallons in the second year program. This would lead to about 10% change in spill losses on a per gallon dispensed basis and about a 1% error in the total loss. Note that this error is compounded by changes in spill loss per refueling that may occur from one region to the next. Spill losses are treated more fully in the discussion of Assumption #10.

Assumption #2 The gallons of fuel dispensed for each refueling operation within each hour varies randomly about some mean value for that day and hour:

This assumption coupled with the first is needed to break away from the individual refueling operations of Equation (4-1) and get to the region wide hourly averages used in Equation (4-2) while maintaining the separability of G and L_R. The assumption seems to be a reasonable one and, therefore, does not appear to contribute to error.

Assumption #3 The number obtained by averaging hourly gallons dispensed per refueling operation over all hours of all days within the period may be substituted for the individual hourly averages:

This assumption allows a single value of gallons dispensed per refueling to be used and allows G expressed as total gallons dispensed per day to be factored out and placed to the left of the summations in the model. The data obtained in the field surveys were not analyzed to determine the presence of any effect of hour of day, or day of week, or day during the period. It seems unlikely, however, that there exists any significant and persistent effect of hour and day that would impact on the model. The question, however, merits further investigation. If an effect were found, it would be no great complication to bring G back within the summations. As was pointed out in Section 4.2 the computer model provides for a variation in G by day.

Assumption #4 The number of refueling operations per hour is a function of the hour of the day but not of the day:

This assumption allows the substitution in Equation (4-3) of the frequency factos $R(h_i)$ for the $R(h_i,d_j)$ values of Equation (4-2). This assumption is supported by the analysis of the field survey data discussed in Section 3.3. As was pointed out the values assigned to the $R(h_i)$ may require alteration from time to time to fit particular situations. It may be necessary in some situations to vary the $R(h_i)$ according to day. The assumption, however, currently included in the model appears reasonably justified by the third year survey data.

Assumption #5 The hourly average hydrocarbon refueling loss per refueling operation can be expressed as the sum of an hourly average hydrocarbon spill loss and an hourly average displaced hydrocarbon loss.

This assumption is adequately supported by the work conducted in the first and second year programs which shows that the two kinds of losses can be treated independently.

Assumption #6 The hourly average spill loss per gallon of dispensed fuel varies randomly about a determinable mean value having no relationship to hour of day or day.

This assumption combined with Assumption #5 is necessary first to express the overall loss as the sum of a spill loss and a displaced loss and second to substitute a single value independent of hour and day for the spill loss. The second year program did not analyze for an effect of hour of day or day. However, the assumption appears to be reasonable and no significant error is expected to result from its use.

Assumption #7 The regional hourly average displaced hydrocarbon loss, $\overline{L}_D'$ can be estimated by a mathematical expression containing the hourly average RVP, the hourly average underground tank temperature, and the hourly average ambient temperature. (This assumption contains within it the assumption that region wide hourly average values of Reid vapor pressure and underground fuel temperature can be used in place of values for each service station within the region.)

This assumption allows a substantial simplification of the expression for $\bar{L}'_D$. The analysis in Sections 2 and 3 show that the displaced HC loss from an individual refueling can be expressed as a function of RVP, T_U and T_A. It must next be determined what errors may result from the use of regional average values for these variables for each hour. Equation(4-17) applies to each individual refueling operation:

$$\bar{L}'_D(h_i,d_j) = \frac{1}{N}\sum_{n_k}^{N(h_i,d_j)} L' \left[T_U(n_k,h_i,d_j),\ T_A(n_k,h_i,d_j),\ P_V(n_k,h_i,d_j)\right] \quad (4\text{-}17)$$

The assumption seeks to substitute in place of Equation 4-17:

$$\bar{L}'_D(h_i,d_j) = L'_D \left[\bar{T}_U(h_i,d_j),\ \bar{T}_A(h_i,d_j),\ \bar{P}_V(h_i,d_j)\right] \quad (4\text{-}18)$$

Since L'_D is an exponential function, Equation (4-18) cannot hold exactly. To see how well the two equations do agree in practice, consider 27 service stations within the region in which P_V, T_U, and T_A at some given hour take on all combinations of two extreme and a mean values for each variable. These values are given by:

	P_V	T_U	T_A
Upper Extreme	10	80	85
Average	9	75	80
Lower Extreme	8	70	75

The Reid vapor pressures of gasolines supplied to a given region might easily vary this much. The underground tank temperature is presumed to range over 10°F because of local differences within the region. It is assumed the range in ambient conditions over the region within a given hour is also 10°F. The displaced HC loss per refill was calculated for each of the 27 different combinations of values using Equation (4-18). The values are shown in Table 4-13. It is seen the average of the 27 calculated displaced HC losses is 6.19 gms. The displaced loss calculated

Table 4-13 Comparison of Average of Displaced Loss with Displaced Loss Calculated from Averages of Independent Variables P_V, T_U, T_A

P_V	T_U	T_A	L'_D
10	80	85	8.19
10	80	80	7.70
10	80	75	7.25
10	75	85	7.51
10	75	80	7.07
10	75	75	6.67
10	70	85	6.89
10	70	80	6.50
10	70	75	6.15
9	80	85	7.05
9	80	80	6.64
9	80	75	6.26
9	75	85	6.50
9*	75*	80*	6.13*
9	75	75	5.79
9	70	85	5.99
9	70	80	5.66
9	70	75	5.36
8	80	85	6.07
8	80	80	5.72
8	80	75	5.40
8	75	85	5.62
8	75	80	5.31
8	75	75	5.02
8	70	85	5.20
8	70	80	4.93
8	70	75	4.67
		Average	6.19

$$\frac{6.19-6.13}{6.19} \times 100 = 1\%$$

* average values of variables

using the regional average values of the variables is underlined in the table and is 6.13 gms/gal. This value is within 1% of the more correct average. Because of the randomness of the variables there is a strong central tendency of the calculated losses, and this tends to account for the closeness of the results. Thus Equation (4-18) appears to be a good approximation of (4-17) and the average hourly values can be used in Equation (4-8) with little loss of accuracy.

It should be noted that because of the exponential nature of the displaced loss equation, the result obtained by using the hourly averages will always be slightly low.

Assumption #8 The hourly average underground fuel temperature is constant within any day:

The underground fuel temperatures are generally stable over a day at any one location and in fact may vary only a few degrees in the course of a month. Use of this assumption allows the substitution of $\overline{T}_U(d_j)$ in place of $\overline{T}_U(h_i,d_j)$. Furthermore, it is unlikely that significant error would be encountered if a constant value of $\overline{T}_U$ were used for periods of up to a month.

Assumption #9 The hourly average Reid vapor pressure is constant within the day:

The Reid vapor pressures of the gasolines supplied to a given location vary slowly over the course of the year between the highest values in the winter and the lowest values in summer and essentially not at all within a given day. As with the underground fuel temperature, the average Reid vapor pressure for a given region can reasonably be considered constant for periods up to a month.

Assumption #10 The average spill loss per gallon of fuel dispensed is 0.30 gms:

This value was determined from the second year field survey. As indicated in the discussion of Assumption #1, spill loss is not fundamentally proportional to gallons of fuel dispensed. Thus as gallons dispensed per refueling varies from region to region the value of the spill loss per gallons dispensed should be adjusted accordingly. In addition to this source of error, which can be as much as 1%, the spill loss per refueling can vary from region to region. Table 4-14 summarizes results of the second year report (Reference 6) for five cities. The spill loss for individual cities is seen to vary from a low of 0.16 gms/gal to a high of 0.49 gms/gal. If these data are an indication of the potential spread, possible errors to the model could be as much as $\pm$ 7% for winter losses $\pm$ 4% for summer losses.

Assumption #11 Equations (2-1), (3-1) and (4-7) provide a reasonable basis for defining $\bar{L}'_D$.

These equations are the basis for the average displaced hydrocarbon loss Equation (4-8) used in the model. The equations will be considered separately and then in terms of their combined effect on the accuracy and applicability of Equation (4-8).

Equation (2-1), developed from the third year laboratory study, was shown in the earlier discussion to strictly apply to partial tank fillings in which somewhat more than half the empty space in the tank was filled. A resulting $\pm$ 3% error in the model was estimated when applied to a distribution of refueling operations. This bias could not be totally avoided since it was desirable to achieve separation of the variables G and L'_R.

Another effect that was not taken into account in the experimental design was that of dispensing a fuel of a given volatility into a vehicle tank containing a fuel of a different volatility. Conditions of different dispensed fuel temperature and vehicle tank fuel temperature, which were studied in the program, generate vapor pressure differences between the incoming fuel and the fuel in the tank which have the same kind of impact as differences in Reid vapor pressure. The RVP differences both enhance

Table 4-14 Summary of Total Spill Losses from Second Year Survey*

City	No. of Cases	Average Refill, (Gallons)	No. of Ref. Operations With Spills	Average Spill Loss, (Grams)	Spill Loss Freq., %	Average Spill Loss (Gms/Refill)	(Gms/gal)
Los Angeles	1005	11.8	392	8.6	39.0	3.3	0.28
Houston	1287	12.8	480	17.0	37.3	6.3	0.49
Chiago	1234	11.7	321	9.8	26.0	2.6	0.22
New York	1515	10.0	546	9.5	36.0	3.4	0.34
Atlanta	1378	11.5	372	6.7	27.0	1.8	0.16
Composite	6419	11.5	2111	10.6	32.9	3.5	0.30

*Reference 6

and detract from the effects of temperature on vapor pressure. In the regional model the effect will, to a large extent, be diminished through the averaging process of the model. Furthermore, the effect will be diminished by the tendency of motorists to remain with a favored brand. From these considerations the probable error is estimated as ± 3%.

The weathering of fuel in vehicle tanks will also lead to differences in volatility between incoming fuel and fuel in the tank. It would tend to generate a systematic negative error because the effect is in one direction. However, there is not sufficient information available at this time to determine the magnitude of the possible error. As a practical matter only one value of RVP appears in Equation (2-1). A two valued equation would be difficult to incorporate into a regional model. Thus, even if the average degree of weathering were known it is not certain whether the values of the RVP entered into the model should be for the weathered fuels in vehicle tanks or that of the dispensed fuels or some weighted average.

A third simplification was involved in the experimental program which led to Equation (2-1). A single fuel tank configuration was used. The second year program did show differences between two commonly used fuel tank types that varied from 0 to 30%. The greatest differences occurred at high temperatures. Thus, a systematic error can be generated if the fuel tank used in the laboratory study is different from the average of the vehicle population of the region. Since the tank studied was a common type it is estimated that the resulting average error in the regional model is ± 10%. It could be higher at the upper temperature bound of the equation.

Given in addition to the above considerations, the high coefficient of determination (R^2 = 94.5%) and the estimated 5.6% regression error percentage for Equation (2-1), it can be concluded that it provides a practical basis for the regional model. However, these same considerations also indicate the equation is much less applicable to individual refueling operations.

Considering next Equation (3-1), it appears to provide an acceptable method of eliminating the dispensed fuel temperature from the model and substituting the more readily measured underground fuel and ambient temperatures. The expression has a high coefficient of determination (R^2 = 98.9%). and a small standard error of estimate of 2.47°F. The analysis in Secion 3 shows

it spans quite well the two geographic areas and three months in which data were collected. Because the data were collected for a limited number of service stations and areas its generality cannot be fully judged. However, its use is not likely to lead to significant error since the analysis shows the main factor in dispensed fuel temperature to be the underground fuel temperature. It alone can account for almost 99% of the observed variance in dispensed fuel temperature. While there may well be other factors as discussed earlier for given service stations configurations and locations, the form of Equation (3-1) and its simplicity make it very suitable for the regional model.

Equation(4.7) which relates initial fuel tank temperature to ambient temperature is of a particularly simple form. It reflects the lack of information concerning the factors determining the effect of ambient conditions and vehicle operation on fuel tank temperatures. The term ΔT in the equation is the average increment above ambient for all cars in a region over the specified period. The discussion given under Assumption #7 shows that the model handles average values quite well. It would be expected, however, that ΔT is a function of the vehicle population, the driving patterns, time of refueling, and ambient temperature. The impact of all these factors could vary with the region and time of year. There is insufficient information available, however, to estimate these effects. The Coordinating Research Council's CAPE 5-68 project (Reference 7) obtained data on fuel system temperatures for a number of cars in the summer and fall of 1969. These data were subsequently analyzed by Scott and applied to driving patterns in four cities. (Reference 9). Using the Scott treatment the temperature increment for each of the cities was estimated to be as follows:

City	ΔT, °F
Los Angeles	6.4
Chicago	6.1
Houston	6.3
New York	6.8
Average	6.4

These calculations show little variation in $\triangle T$ among the four cities. A value of $\triangle T$ of 6 to 7 is the best current estimate for use in the regional model.

It is of interest to determine the sensitivity of the model to the choice of $\triangle T$. The table below shows the average refueling loss for the winter and summer cases with $\triangle T$ varying 5°F above and below the optimum value of 7°F.

$\triangle T$ (°F)	Average Refueling Loss (gms/gal) Summer	Winter
12	5.25	3.13
7	5.08	3.10
2	4.92	3.07

It is seen that for the summer period the 5° change results in about a $\pm$ 3% change while for the winter period the change is about $\pm$ 1%. The model, therefore, appears to be relatively insensitive to the precise choice of $\triangle T$.

The above considerations lead to the conclusion that the form of Equation (4.7) with $\triangle T$ = 6° to 7° is a good first approximation and will not lead to substantial error.

The discussion of the base equations which give rise to the average estimated displaced hydrocarbon loss expression Equation (4-8), lead to the general conclusion that the model rests on a sound basis and should give reasonably accurate answers. It would not be appropriate, however, to apply any of the three base equations nor the composite equation to a single refueling operation.

The regression error or error of estimate in Equation (4-8) is a combination of the errors in the base equations. The errors combine approximately as follows:

Equation (2-1) has the form:

$$\ln L_D' = a + bP_V T_D + cT_T + dP_V + eT_D T_T$$

The following approximation can then be made of the overall standard error of estimate when Equations (3-1) and (4-7) are substituted into (2-1) to yield Equation (4-8):

$$E(\ln\bar{L}'_D) = E^2(\ln L'_D) + (bP\ E(T_D))^2 + (cE\ (T_T))^2 + (eE(T_D)E(T_T))^2 \qquad (4\text{-}19)$$

where

$E(\ln\bar{L}'_D)$ = The standard error of estimate for Equation (4-8)

$E(\ln L'_D)$ = The standard error of estimate for Equation (2-1)

$E(T_D)$ = The standard error of estimate for Equation (3-1)

$E(T_T)$ = The standard error of estimate for Equation (4-7)

The regression analyses give $E(\ln L'_D) = 0.056$, and $E(T_D) = 2.5$. Additionally it is assumed that $E(T_T) = 7$ which is almost certainly too high. It is further assumed that the error in the term $T_D T_T$ is reasonably approximated by product of the respective standard errors of estimate. If these values are substituted into Equation (4-19) along with the appropriate constants from Equation (2-1) we have:

		Squares
$E(\ln L'_D)$	= 0.056	3.136×10^{-3}
$bP_V E(T_D)$	= 0.0287	0.827×10^{-3}
$cE(T_T)$	= 0.0088	0.079×10^{-3}
$eE(T_D)E(T_T)$	= 0.00188	0.004×10^{-3}
		4.046×10^{-3}

$$E(\bar{L}'_D) = \sqrt{4.046 \times 10^{-3}} = 0.064$$

Thus the percentage error in going from the displaced loss equation given by Equation (2-1) to that given by Equation (4-8) only increases from 5.6% to 6.4%. It can also be seen from the above tabulation that a large error of estimate assumed for T_T does not have a large impact on the overall error. This further supports the use of Equation (4-7).

There is also room for a large error in the term $T_D T_T$ so that the estimate $E(T_D)E(T_T)$ is reasonably safe.

In addition to the model error there is the possible error resulting from selecting incorrect values of the variables to be input to the model. The sensitivity of the model to changes in the variables has already been partially explored in the previous discussion. To further explore the sensitivity, calculations were performed to show the effects of misestimates of all the variables acting simultaneously and individually. For this purpose it was sufficient to use Equation (4-16), the most abreviated form of the model.

The results are shown in Table 4-15 and 4-16 for both warm and cold 31 day periods. In Table 4-15, the middle values in each of the two cases were taken as the estimated values of the variables. It is assumed the set of values just above the middle values are correct in one situation and those below are correct in the other situation.

It is seen in the warm temperature case a $\pm$ 31% error was incurred in the estimate of grams loss per gallon and a -37 to + 48% error in the estimate of pounds lost over the 31 day period. In the cold temperature case the error in grams lost per gallon was $\pm$ 27%. These are substantial errors and indicate the need for care in estimating the input values. Of course, it is unlikely that all the variables would err in the same direction by the amounts shown.

The effects of misestimates of individual variables in Table 4-16 show errors ranging from 0.6 to 11.5%. The model is most sensitive to misestimates of Reid vapor pressure and underground fuel temperature but the somewhat lower sensitivity to the ambient temperature is accounted for by the smaller change allowed in that variable. The model is least sensitive to the ΔT value. The gallons dispensed per day was not included in the table since the resulting model error in this case is equal to the percentage error in the estimate of gallons dispensed.

The error and sensitivity analysis discussed in this section is summarized in Table 4-17. The combination of all the estimated errors intrinsic to the model was estimated to be 14%. This estimate was obtained by assuming the variances from each source of error are additive. If

Table 4-15 Sensitivity Analysis of Refueling Loss Model-
Combined Effect of Variables

$\bar{\bar{P}}_V$	$\bar{\bar{T}}_U$	$\bar{\bar{\bar{T}}}_A$	ΔT	$\bar{G}/10^6$	Total Refueling Loss	
					Gms/gal	Pounds (31 days)
9	73	70	12	1.10	6.09	458,000
8	65	65	7	1.00	4.23	289,000
7	57	60	2	0.90	3.21	197,000
13	38	35	12	1.10	3.98	299,000
12	30	30	7	1.00	3.14	214,000
11	22	25	2	0.90	2.56	157,000

Table 4-16 Sensitivity Analysis of Refueling Loss Model
Effect of Individual Variables

Variable Altered	$\bar{\bar{P}}_V$	$\bar{\bar{T}}_U$	$\bar{\bar{T}}_A$	ΔT	Refueling Loss (Gms/gal)	%Difference
-	8	65	65	7	4.23	-
$\bar{\bar{P}}_V$	9	65	65	7	4.78	11.5
$\bar{\bar{T}}_U$	8	73	65	7	4.69	9.8
$\bar{\bar{T}}_A$	8	65	70	7	4.43	4.5
ΔT	8	65	65	12	4.35	2.8
-	12	30	30	7	3.14	-
$\bar{\bar{P}}_V$	13	30	30	7	3.40	7.6
$\bar{\bar{T}}_U$	12	38	30	7	3.48	9.8
$\bar{\bar{T}}_A$	12	30	35	7	3.22	2.5

Table 4-17 Summary of Error and Sensitivity Analysis of the Regional Model

Errors Intrinsic to Model	
o Dependence of displaced HC loss on volume dispensed	± 3%
o Lack of representativeness of fuel tank used to obtain displaced HC loss data for a given region	± 10%
o Differences in volatility of dispensed fuel and fuel in tank	
- Base difference in Rvp	± 3%
- From weathering of fuel in tank	no info.
o Incorrect dependence of spill loss on gallons dispensed (due to incorrect estimate of average gallons dispensed per refueling)	± 1%
o Incorrect estimate of average spill loss per refueling for a given region	± 5%
o Substitution of average values of independent variables in displaced HC loss equation instead of taking average of losses	-1%
o Unexplained variance in $\overline{L}_D'$ (Eqn. 4-8)	6.4%
o Overall, combined error	14%
Errors from Incorrect Choice of Input Variable	
o Reid vapor pressure, 1 lb error	± 10%
o Underground fuel tank temperature, 8°F error	± 10%
o Ambient temperature, 5°F error	± 4%
o ΔT, 5°F error (not strictly an input variable)	± 2%
o Gallons dispensed, 10% error	10%
All variables in error in same direction	±21-32% (Gms/gal) +26-47% (Total pounds)

it is assumed that the errors from the incorrect choice of input variables occur randomly, about 18% error is estimated for this source. The overall estimate of the standard error for the use of the model is about 23%. It should be emphasized, however, that while the user cannot do much about the intrinsic errors in the model, he can use care in determining the input variables and thus take maximum advantage of the model's inherent accuracy.

As a final consideration it should be noted that the ranges of the input variables are restricted by the constraints placed on the original input variables to the displaced HC loss expression Equation (2-1).

Rvp (psi)	Range of Functions $T + 7$ and $0.81\ T_U + 0.23\ T_A - 1.2$
7	50 - 90
10	40 - 80
13	30 - 70

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5. "Investigation of Passenger Car Refueling Losses"; Scott Research Laboratories, Inc., March 6, 1970.

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9. "Mathematical Expressions Relating Evaporative Emissions From Motor Vehicles Without Evaporative Loss Control Devices to Gasoline Volatility"; W. F. Biller, M. Manoff, et.al, SAE Paper 720700 SAE National West Coast Meeting, August 1972.

APPENDIX A

FUEL INSPECTION DATA

Table A-1

Fuel Inspection Data

(Measurements Made by the Ethyl Corporation, Long Beach, California)

	Sample 6-31	Sample 16-61	Sample 32-111
Nominal RVP, psi	7	10	13
Measured RVP, psi	7.2	9.7	12.2
FIA, % Aromatics	35.0	35.0	29.0
% Olefins	2.0	2.0	2.0
% Saturates	63.0	63.0	69.0
Distillation Data, °F			
Initial Boiling Point	98	97	84
5% Evaporated	122	114	93
10% Evaporated	137	125	103
15% Evaporated	150	134	111
20% Evaporated	165	143	118
30% Evaporated	187	162	135
40% Evaporated	208	182	154
50% Evaporated	228	204	173
60% Evaporated	252	228	195
70% Evaporated	284	255	222
80% Evaporated	320	284	256
90% Evaporated	360	310	298
95% Evaporated	391	337	340
Final Boiling Point	428	398	382
Recovery, percent	98.8	98.0	97.0
Residue, percent	1.0	0.6	0.6
Loss, percent	0.2	1.4	2.4

APPENDIX B

LABORATORY DATA

TABLE B-1. LABORATORY DATA

CASE NUMBER	******** TEMPERATURE - DEGREES FAHRENHEIT ********* AVERAGE DISP FUEL	INITIAL TANK FUEL	MINI-SHED AMBIENT	AVERAGE VAPOR	RVP (PSI)	DISPLACED LOSS (GMS/GAL)
1	85	83	89	91	6.8	4.37
2	81	89	91	94	6.1	4.48
3	87	98	83	90	6.1	4.90
4	84	84	88	92	6.8	4.52
5	80	80	85	88	6.8	4.34
6	75	85	90	93	6.6	4.34
7	76	89	89	90	6.6	4.12
8	68	83	86	90	6.6	3.79
9	64	62	56	89	6.6	3.39
10	73	87	89	90	6.2	3.91
11	60	84	83	89	6.2	3.21
12	60	76	76	80	7.1	3.06
13	67	78	80	82	7.1	3.56
14	66	76	75	80	7.0	3.42
15	70	71	76	79	6.9	3.52
16	74	74	80	82	6.7	4.00
17	76	77	79	82	6.7	4.21
18	75	80	79	84	6.4	4.39
19	82	76	76	79	6.4	4.44
20	82	70	70	70	6.8	3.93
21	85	70	70	72	6.8	4.18
22	80	72	70	74	6.8	4.04
23	80	70	70	72	6.8	3.93
24	72	63	70	71	6.8	3.60
25	73	70	71	71	6.8	3.56
26	68	63	70	71	6.7	3.20
27	66	68	72	71	6.7	3.18
28	64	68	70	68	7.0	3.04
29	58	63	70	65	7.0	2.82
30	58	60	56	60	7.2	2.65

TABLE B-1 (CONTINUED). LABORATORY DATA

CASE NUMBER	******** TEMPERATURE - DEGREES FAHRENHEIT ********* AVERAGE DISP FUEL	INITIAL TANK FUEL	MINI-SHED AMBIENT	AVERAGE VAPOR	RVP (PSI)	DISPLACED LOSS (GMS/GAL)
31	56	60	58	59	7.2	2.63
32	56	60	58	58	6.9	2.64
33	60	60	58	61	6.9	2.85
34	64	60	59	63	7.2	3.20
35	66	60	70	64	7.2	3.36
36	70	60	70	65	6.9	3.63
37	76	60	71	70	6.8	4.12
38	81	61	70	71	6.8	4.37
39	79	49	50	58	6.9	3.40
40	85	50	50	55	6.8	3.89
41	69	50	50	53	7.0	2.92
42	72	50	50	54	7.0	3.12
43	73	50	50	56	7.0	3.34
44	70	52	52	57	7.0	3.11
45	60	55	52	56	6.9	2.73
46	63	54	52	56	6.9	2.94
47	59	52	49	54	6.9	2.75
48	57	53	50	55	6.9	2.66
49	71	45	43	52	9.5	4.59
50	72	45	43	55	9.6	4.48
51	68	45	42	52	9.7	4.31
52	63	44	42	51	9.8	3.62
53	56	41	40	47	9.8	3.53
54	55	42	41	46	9.6	3.51
55	53	42	40	46	9.5	3.46
56	48	41	40	45	10.0	3.25
57	45	41	40	45	10.0	3.14
58	46	47	46	48	9.7	3.35
59	42	45	46	48	9.7	3.22
60	46	45	46	49	9.9	3.23

TABLE B-1 (CONTINUED). LABORATORY DATA

CASE NUMBER	******** TEMPERATURE - DEGREES FAHRENHEIT ********* AVERAGE DISP FUEL	INITIAL TANK FUEL	MINI-SHED AMBIENT	AVERAGE VAPOR	RVP (PSI)	DISPLACED LOSS (GMS/GAL)
61	50	46	47	51	9.9	3.55
62	55	48	48	52	9.8	3.75
63	59	47	47	52	9.8	4.05
64	61	48	48	54	10.0	4.05
65	66	48	47	54	10.0	4.59
66	68	48	48	54	9.9	4.53
67	74	48	48	58	9.9	5.26
68	72	61	62	66	9.9	5.74
69	73	61	62	65	10.0	5.24
70	70	62	62	63	10.0	5.01
71	64	65	60	63	10.0	4.41
72	61	64	59	61	10.0	4.29
73	60	63	60	61	9.7	3.89
74	54	62	59	59	9.7	3.79
75	51	61	58	58	9.7	3.60
76	48	61	60	58	9.7	3.39
77	53	66	68	66	9.8	3.99
78	49	64	66	62	9.8	3.52
79	52	66	66	63	9.8	3.66
80	53	65	65	64	9.8	3.63
81	61	66	66	64	10.0	4.28
82	60	66	66	65	10.0	4.49
83	63	66	67	69	9.8	4.75
84	66	66	66	68	9.8	4.93
85	71	66	66	70	9.7	5.45
86	76	66	69	71	9.7	6.18
87	77	74	79	80	9.7	6.09
88	78	72	79	76	9.7	6.48
89	75	73	78	76	9.8	6.04
90	68	75	79	79	9.7	5.40

TABLE B-1 (CONTINUED). LABORATORY DATA

CASE NUMBER	******** TEMPERATURE - DEGREES FAHRENHEIT ********* AVERAGE DISP FUEL	INITIAL TANK FUEL	MIN-SHED AMBIENT	AVERAGE VAPOR	RVP (PSI)	DISPLACED LOSS (GMS/GAL)
91	68	77	81	76	9.7	5.35
92	63	76	80	77	9.6	4.95
93	63	76	80	77	9.6	4.73
94	70	72	70	70	12.6	7.10
95	70	71	68	73	12.6	8.08
96	66	70	63	69	12.9	7.16
97	64	65	68	68	12.9	6.97
98	56	65	68	67	12.8	5.64
99	52	64	67	69	12.8	5.02
100	55	68	69	71	12.9	5.29
101	47	65	65	68	12.9	4.18
102	51	60	57	58	12.5	4.52
103	41	58	55	56	12.5	3.63
104	41	57	57	59	12.5	3.47
105	43	57	57	57	12.5	3.97
106	52	59	59	62	12.5	4.70
107	50	58	59	61	12.5	4.99
108	56	59	60	62	12.5	5.95
109	58	57	59	60	12.5	6.05
110	63	54	58	61	12.5	5.90
111	68	54	58	62	12.5	6.64
112	68	46	46	54	12.2	5.93
113	62	47	47	52	12.2	5.28
114	59	45	46	51	12.2	5.41
115	53	45	46	50	12.2	4.52
116	50	45	47	49	12.3	4.38
117	46	45	46	49	12.3	4.12
118	41	43	46	46	12.4	3.67
119	36	49	47	46	12.4	3.27
120	34	49	47	47	12.5	3.14

TABLE B-1 (CONTINUED). LABORATORY DATA

CASE NUMBER	******** TEMPERATURE - DEGREES FAHRENHEIT ********* AVERAGE DISP FUEL	INITIAL TANK FUEL	MINI-SHED AMBIENT	AVERAGE VAPOR	RVP (PSI)	DISPLACED LOSS (GMS/GAL)
121	42	50	48	50	12.5	3.76
122	40	41	39	42	12.5	3.54
123	31	41	38	40	12.5	3.35
124	35	43	40	42	12.2	3.52
125	36	42	39	42	12.2	3.65
126	43	40	39	42	11.9	3.87
127	47	40	38	43	11.9	4.21
128	53	40	38	41	12.6	4.56
129	58	40	38	46	12.6	5.21
130	58	39	37	40	12.5	4.73
131	64	40	37	43	12.5	5.68
132	61	31	30	34	12.4	5.13
133	54	30	27	27	12.5	4.11
134	51	31	28	30	12.5	3.70
135	47	31	30	28	12.6	3.87
136	42	32	29	26	12.6	3.47
137	40	33	31	26	12.7	3.68
138	35	31	26	22	12.6	3.13
139	33	36	31	25	12.6	3.07
140	38	37	30	24	12.6	3.19

APPENDIX C

STANDARD ERROR

Standard Error as Percent Error

In computing the standard error of the estimate for a logarithmic fit, the residuals are given as the natural log of the measured loss, $\ln L_m$, minus the natural log of the regression estimate, $\ln L_D'$. Let that residual be denoted by R so that

$$R = \ln L_m - \ln L_D'$$

In units of grams/gallon, let the residual be

$$\Delta L = L_m - L_D'.$$

Then

$$L_m = L_D' e^R$$

$$\Delta L = L_m - L_D' = L_D' (e^R - 1).$$

Denoting the residual as R% in percentage units,

$$R\% = \frac{\Delta L}{L_m} \times 100 = 100 (1-e^{-R}).$$

For small R, $e^{-R} \approx 1-R$. Thus, $R\% \approx 100R$.

Each residual is thus convertible to an approximate error percentage. Therefore, the standard error of the estimate is in units of percentage error.

APPENDIX D

SAMPLE TEMPERATURE DATA FROM THE THIRD YEAR FIELD SURVEY

TABLE D - 1 THIRD YEAR FIELD SURVEY TEMPERATURE DATA

STATION: 2 SAN BERNARDINO - ONTARIO DATE: 8 25 72

TIME	AMBIENT	UNDERGROUND FUEL	TEMPERATURES, DEG F ••DISPENSED FUEL•• AVG.	INITIAL	FINAL	••DISPLACED VAPOR•• AVG.	INITIAL	FINAL
655	64	83.7	73.0	65.0	78.0	71.5	67.0	75.0
701	64	83.7	82.0	78.0	84.0	78.0	74.0	81.5
748	64	83.9	82.5	74.0	84.0	78.0	74.0	80.0
752	64	83.9	71.0	68.0	75.0	70.5	67.5	72.5
816	64	84.0	82.5	73.0	84.0	81.0	73.0	83.5
833	64	83.8	75.5	68.5	79.5	70.0	68.0	73.0
837	64	84.0	83.5	80.0	84.5	81.0	74.5	83.0
839	64	84.0	85.0	82.0	85.5	82.0	80.0	83.5
902	65	83.9	83.0	70.0	86.0	72.5	70.0	76.0
905	65	83.9	84.0	73.0	86.0	75.5	72.0	78.0
911	65	84.0	81.0	72.0	82.5	75.5	74.0	76.5
916	65	83.8	83.5	76.0	85.0	85.5	74.5	82.5
930	66	84.0	83.5	73.5	84.5	79.5	76.0	82.0
945	66	83.6	86.0	85.0	86.0	79.0	76.0	80.5
951	66	84.0	85.0	71.5	86.0	81.5	74.0	84.0
957	64	83.5	81.5	78.0	82.0	75.0	73.0	76.0
1015	67	83.6	84.5	75.5	85.0	85.0	78.0	84.5
1017	67	83.6	75.5	74.0	78.5	77.0	72.5	82.5
1103	70	84.0	85.0	85.0	85.0	83.0	82.0	83.5
1107	70	84.0	84.5	77.0	84.0	82.5	75.0	83.5
1114	71	84.0	84.0	77.0	84.5	82.0	75.0	83.0
1127	72	84.0	82.5	76.0	84.5	80.0	77.0	82.0
1134	72	84.0	84.0	84.0	84.5	82.5	80.5	83.0
1139	73	84.0	84.5	86.0	84.5	81.0	80.0	82.0
1151	73	84.0	84.0	80.0	84.0	81.0	80.0	81.0
1157	73	84.0	83.5	77.0	82.0	79.0	77.0	75.0
1158	73	84.0	82.5	83.0	83.0	82.0	82.0	82.0
1201	74	84.0	84.0	83.5	84.0	84.0	81.0	84.0
1203	74	84.0	82.5	79.0	84.0	84.0	80.0	85.0
1219	75	84.0	83.0	84.0	85.5	80.5	82.0	79.5
1244	76	84.0	84.0	79.5	85.0	80.5	83.0	79.0
1253	76	84.0	85.0	81.0	85.0	86.0	81.0	85.5
1303	77	84.0	84.5	83.0	84.5	83.0	84.0	82.5
1306	77	84.0	84.5	81.5	86.0	85.0	82.0	86.0
1310	78	84.0	84.0	83.5	84.5	84.5	84.0	88.0
1318	78	84.0	85.0	82.0	86.0	81.5	81.0	82.0
1339	80	84.0	85.0	84.5	86.0	85.0	84.0	86.0
1350	81	84.0	87.0	85.0	87.5	87.5	87.0	88.0
1353	81	84.0	86.5	86.5	86.5	89.0	88.5	89.0

TABLE D - 1 CONTINUED

STATION: 2 SAN BERNARDINO - ONTARIO DATE: 8 25 72

TIME	AMBIENT	UNDERGROUND FUEL	TEMPERATURES, DEG F ••DISPENSED FUEL•• AVG.	INITIAL	FINAL	••DISPLACED VAPOR•• AVG.	INITIAL	FINAL
1400	81	84.0	86.5	85.0	88.0	87.5	84.5	89.5
1407	82	84.0	86.0	84.0	86.0	80.5	83.0	80.0
1411	82	84.0	88.0	87.0	85.0	86.5	86.0	86.5
1413	82	84.0	84.0	83.0	88.0	87.5	86.0	86.0
1420	81	84.0	86.0	85.0	86.0	88.0	84.0	86.0
1422	81	84.0	86.5	85.0	86.5	86.5	85.0	87.5
1427	82	84.0	85.5	86.0	85.0	84.0	87.0	86.0
1505	82	84.0	85.5	85.0	86.0	86.5	86.0	86.5
1529	83	84.0	86.5	87.0	87.0	89.5	87.0	92.0
1536	83	84.0	85.5	84.0	85.5	87.0	88.5	87.0
1543	83	84.0	87.5	86.5	88.0	87.5	86.5	88.0
1549	83	84.0	86.0	83.0	86.0	98.5	94.0	103.0
1550	83	84.0	88.0	90.0	86.0	88.5	91.0	88.0
1600	84	84.0	87.0	86.5	87.5	91.0	87.0	90.0
1612	84	84.0	85.5	86.0	85.5	90.0	86.0	90.0
1617	84	83.9	89.0	85.5	86.0	86.5	86.0	89.0
1621	84	84.0	86.5	86.0	86.0	89.5	90.5	89.0
1626	84	83.9	88.0	88.0	88.0	91.0	89.5	90.0
1629	84	84.0	86.0	88.0	86.0	87.5	89.5	86.5
1650	83	84.0	85.0	90.0	85.0	90.0	92.5	92.0
1653	83	83.5	87.5	88.0	87.5	89.0	88.0	88.0
1704	82	84.0	87.5	86.0	88.0	88.5	88.5	88.0
1707	82	83.4	86.5	86.0	85.5	89.0	89.0	87.5
1713	82	83.4	87.5	86.5	87.5	88.5	86.5	90.0
1717	82	84.0	85.5	85.0	85.5	92.0	86.0	91.5
1721	82	83.3	85.5	86.0	86.5	85.5	86.0	86.0
1726	81	84.0	86.0	86.0	85.5	87.5	86.0	87.0
1732	80	83.2	86.0	86.0	86.0	87.0	85.0	88.0
1737	80	84.0	85.5	85.0	85.5	85.0	83.5	86.5
1740	79	83.1	85.5	82.5	86.0	86.0	85.0	86.0
1742	79	83.1	86.0	86.0	86.0	86.0	75.0	88.0
1855	74	84.0	86.0	84.0	86.5	86.0	85.0	86.5
1858	74	83.0	85.5	78.0	86.5	85.0	81.0	86.0
1904	74	84.0	84.0	78.0	84.0	84.0	84.0	84.5
1909	74	83.0	84.0	78.0	85.0	84.0	78.0	85.5
1915	73	83.0	86.0	82.0	86.5	83.0	76.0	84.0
1926	72	84.0	85.5	76.0	87.0	85.0	79.0	87.0
1929	72	83.0	86.0	85.5	87.0	82.0	81.5	82.5
			84.5	78.0	85.5	78.0	78.0	78.0

TABLE 2 - 1 CONTINUED

STATION: 2 SAN BERNARDINO - ONTARIO DATE: 8 25 72

TIME	AMBIENT	UNDERGROUND FUEL	TEMPERATURES, DEG F DISPENSED FUEL AVG.	DISPENSED FUEL INITIAL	DISPENSED FUEL FINAL	DISPLACED VAPOR AVG.	DISPLACED VAPOR INITIAL	DISPLACED VAPOR FINAL
1928	72	84.0	86.5	85.0	86.0	84.5	81.0	85.0
1935	72	83.0	85.0	79.0	84.0	81.0	76.5	83.0
1939	71	83.0	86.5	82.0	86.5	84.5	74.5	85.0
1948	71	83.0	86.5	75.0	88.0	81.0	77.0	82.0
1955	70	83.0	85.0	78.0	86.0	83.5	78.0	85.0
2000	70	83.0	85.5	80.5	85.5	83.5	80.0	85.0
2009	70	83.0	86.5	79.0	87.5	80.0	78.0	82.0
2021	69	83.0	85.0	80.0	86.0	80.5	77.0	83.0
2035	69	83.0	84.0	78.0	85.0	79.0	78.0	80.0
2040	68	84.0	83.5	83.0	86.0	81.5	78.0	84.0
2047	68	83.0	83.5	73.0	85.0	80.0	74.0	82.0
2054	68	83.0	85.5	82.0	85.0	83.0	77.0	85.0
2118	69	83.0	83.0	82.0	84.0	79.5	78.0	80.5

TABLE D - 2 THIRD YEAR FIELD SURVEY TEMPERATURE DATA

STATION: 6 MINNEAPOLIS - ST PAUL DATE: 1 21 73

TIME	TEMPERATURES, DEG F							
	AMBIENT	UNDERGROUND FUEL	DISPENSED FUEL			DISPLACED VAPOR		
			AVG,	INITIAL	FINAL	AVG,	INITIAL	FINAL
657	24	34,5	34,0	33,5	34,0	32,0	32,0	32,0
724	24	34,6	33,0	28,0	34,0	31,5	28,5	32,0
744	24	34,6	33,5	28,0	34,0	30,5	29,0	32,0
945	24	35,0	32,0	29,0	35,0	34,5	31,0	35,5
1005	24	35,0	32,5	31,0	34,0	31,5	31,0	32,0
1034	25	35,0	33,0	32,5	34,0	32,5	30,0	33,5
1042	25	35,0	34,5	34,0	35,0	37,5	32,5	38,0
1135	27	35,1	34,5	38,5	34,0	32,5	35,5	32,0
1140	27	35,0	33,0	33,0	33,0	36,0	33,0	36,5
1149	27	35,2	34,5	35,0	35,0	34,0	32,0	32,5
1150	27	35,0	34,0	38,0	35,5	35,0	39,0	36,0
1228	28	35,3	34,5	36,0	34,0	35,5	37,5	34,0
1235	28	35,3	35,0	36,0	34,5	37,5	39,0	36,5
1258	29	35,4	36,0	36,0	36,0	34,5	34,0	34,5
1317	28	35,0	33,5	35,0	34,0	35,5	33,0	35,0
1340	29	35,0	35,0	36,5	35,0	36,5	37,0	35,5
1342	29	35,4	35,5	41,5	35,5	43,5	42,0	42,0
1344	29	35,4	35,0	35,0	35,0	36,5	38,0	35,5
1349	29	35,3	35,0	35,0	35,0	35,5	34,0	35,0
1415	29	35,2	35,0	36,0	35,0	37,0	39,0	36,0
1431	29	35,2	35,5	37,0	35,0	37,0	37,0	36,5
1437	29	35,1	35,5	35,5	35,0	35,0	35,0	34,0
1446	29	35,1	35,5	35,5	35,0	44,5	39,0	44,0
1450	29	35,1	35,0	35,0	34,5	36,0	35,0	35,5
1459	28	35,0	33,5	33,0	34,0	34,0	30,5	35,8
1500	28	35,0	35,0	35,0	35,5	37,0	39,0	37,0
1525	29	35,2	35,0	35,5	35,0	39,5	36,0	39,0
1530	28	35,2	35,0	32,5	35,0	35,0	33,5	35,0
1531	28	35,2	35,5	35,0	36,5	37,5	37,0	37,5
1533	28	35,1	34,5	34,0	34,5	33,0	34,0	33,0
1535	28	35,2	35,0	32,0	34,5	32,5	31,0	33,5
1540	28	35,3	35,0	34,0	35,0	34,0	33,5	34,0
1542	28	35,3	36,5	35,0	36,5	40,0	35,0	41,5
1622	28	35,6	34,5	31,0	35,0	33,5	31,0	35,0
1644	28	35,8	34,0	32,0	34,0	32,5	32,0	33,0
1651	28	35,9	34,0	32,0	34,5	33,0	31,0	33,0
1654	28	35,4	35,0	32,0	34,5	34,5	27,5	36,0
1657	28	35,9	34,5	28,5	34,5	32,5	27,5	33,0
1710	28	36,0	34,5	32,0	34,0	32,0	30,0	32,0

TABLE D - 2 CONTINUED

STATION: 6 MINNEAPOLIS - ST PAUL DATE: 1 21 73

TIME	AMBIENT	UNDERGROUND FUEL	TEMPERATURES, DEG F ***DISPENSED FUEL*** AVG.	INITIAL	FINAL	**DISPLACED VAPOR** AVG.	INITIAL	FINAL
1714	28	36.0	34.5	33.0	35.0	31.5	33.0	39.0
1731	28	36.0	35.0	32.0	35.0	33.0	33.5	33.5
1740	28	36.0	35.0	34.0	35.0	33.0	33.0	32.5
1751	28	36.0	35.0	35.5	35.0	33.5	35.5	32.5
1759	28	36.0	34.5	33.0	34.5	33.5	31.5	33.5
1800	28	36.0	35.5	34.0	35.0	44.5	42.5	46.0
1805	28	36.0	34.5	32.5	35.0	36.5	33.0	36.5
1820	28	36.0	35.5	33.5	35.5	38.5	34.5	39.0
1823	28	36.0	34.5	32.0	35.0	32.5	30.0	32.5
1827	28	36.0	34.5	31.0	35.0	34.0	29.5	34.0
1830	28	35.8	33.0	31.0	34.0	31.0	29.5	31.0
1846	28	36.0	34.5	31.5	35.0	33.5	29.5	33.5
1852	28	35.9	33.0	31.0	34.0	33.5	33.0	34.0
1857	28	36.0	35.0	32.5	34.5	32.5	30.0	33.0
1901	28	36.0	35.5	35.0	35.5	35.0	35.0	34.0
1938	28	35.7	33.0	31.0	34.0	35.0	32.0	35.5
1940	28	35.7	34.5	31.5	35.0	36.5	30.0	36.5
1942	28	35.7	35.5	35.5	35.5	36.5	35.5	36.5
1947	28	35.7	35.0	32.5	35.0	32.5	30.5	32.5
1950	28	35.6	35.0	34.0	35.5	38.5	30.0	38.5
1956	28	35.6	35.5	35.5	35.5	36.0	36.5	35.5
2006	28	35.5	35.0	34.0	35.0	37.5	31.5	38.0
2010	28	35.5	34.5	34.0	35.0	33.5	34.0	33.5
2014	28	35.4	35.0	33.0	35.5	36.0	30.0	36.5
2024	28	35.4	34.5	32.0	34.0	34.5	30.5	34.0
2030	28	35.3	34.5	33.0	34.5	37.5	33.0	36.5
2039	28	35.2	34.0	32.5	34.0	33.5	30.5	33.5
2047	28	35.2	35.0	31.0	34.5	35.0	30.5	34.5
2050	28	35.1	35.0	34.0	35.0	34.0	32.0	33.0
2100	28	35.0	35.0	34.0	35.0	35.5	32.0	35.5
2103	28	35.0	35.0	35.0	35.0	34.0	34.5	34.0
2120	28	35.0	35.0	33.0	35.5	37.5	34.0	37.5
2140	28	35.0	35.0	33.0	35.0	35.5	34.5	36.0
2142	28	35.0	35.0	32.0	34.5	34.5	35.0	34.0
2146	28	35.0	34.5	33.5	34.5	32.5	31.5	33.0
2154	28	35.0	33.5	33.5	33.5	33.5	33.5	33.5

TABLE D - 3 THIRD YEAR FIELD SURVEY TEMPERATURE DATA

STATION: 7 SAN BERNARDINO - ONTARIO DATE: 3 27 73

TIME	TEMPERATURES, DEG F							
	AMBIENT	UNDERGROUND FUEL	**DISPENSED FUEL**			**DISPLACED VAPOR**		
			AVG,	INITIAL	FINAL	AVG,	INITIAL	FINAL
735	47	67,6	55,5	49,5	56,5	51,5	50,0	52,0
806	47	67,0	57,0	50,0	60,0	54,0	51,0	57,0
813	47	66,0	56,0	51,0	60,0	55,5	52,0	58,0
813	47	66,0	53,0	50,0	55,0	53,5	53,0	54,0
854	47	67,9	56,0	53,0	57,0	51,5	51,0	52,0
902	47	68,0	58,5	53,5	60,0	55,0	52,0	56,0
903	47	68,0	53,0	50,0	54,5	51,0	51,0	51,0
933	47	66,1	57,0	52,5	59,0	55,0	52,5	57,0
936	47	68,0	59,5	52,5	60,0	57,0	51,5	59,0
941	48	68,0	62,0	56,0	64,0	57,5	54,0	59,5
1000	48	69,0	61,5	56,0	62,5	56,5	53,5	57,5
1008	48	68,0	58,0	52,0	61,0	57,5	55,0	60,0
1023	49	67,0	58,0	53,5	59,0	55,5	54,0	57,0
1035	49	68,0	61,0	54,5	62,0	57,5	53,5	59,0
1041	49	66,4	61,0	55,0	63,0	61,0	56,0	62,5
1047	49	66,4	63,0	60,0	63,5	60,5	53,0	62,5
1048	49	66,4	57,0	54,0	61,0	55,5	54,0	57,0
1125	49	67,0	56,5	52,0	57,0	53,5	52,0	55,0
1128	49	68,0	58,5	52,0	60,0	57,0	53,5	59,0
1204	49	67,0	56,0	51,5	57,0	53,0	52,5	54,0
1211	49	67,0	57,5	53,0	61,0	57,0	53,0	59,0
1212	49	68,0	61,0	54,0	63,0	56,0	54,0	58,5
1239	50	67,0	57,0	54,0	58,0	54,5	53,0	55,0
1248	50	66,0	58,0	54,0	60,0	58,0	54,0	60,0
1249	50	68,0	60,5	54,0	62,0	55,5	53,0	56,0
1251	50	66,5	57,5	53,5	58,0	55,0	53,0	57,0
1310	50	69,0	58,5	54,0	59,0	56,5	54,0	57,5
1317	50	68,0	60,5	55,5	63,0	59,0	55,5	61,0
1320	50	66,5	58,5	54,0	60,0	65,0	54,0	65,0

TABLE D - 4 THIRD YEAR FIELD SURVEY TEMPERATURE DATA

STATION: 7 SAN BERNARDINO - ONTARIO DATE: 4 5 73

TIME	AMBIENT	UNDERGROUND FUEL	TEMPERATURES, DEG F DISPENSED FUEL			DISPLACED VAPOR		
			AVG.	INITIAL	FINAL	AVG.	INITIAL	FINAL
648	53	67.5	62.5	58.0	64.0	59.0	55.5	56.0
650	53	67.5	66.0	62.5	67.0	62.5	57.5	63.5
655	53	65.5	58.0	55.5	59.0	59.5	57.0	61.5
714	58	67.6	62.5	65.0	65.5	62.5	62.0	63.0
816	61	68.1	66.5	65.0	67.0	66.0	65.0	66.5
817	62	65.8	67.0	66.0	67.0	66.0	65.0	67.0
833	63	65.8	67.0	66.0	68.0	66.0	66.5	66.5
847	64	65.9	68.0	67.5	68.0	67.0	68.5	67.0
852	64	68.4	68.0	66.5	68.5	67.5	66.5	68.0
904	66	68.5	66.5	68.0	65.0	66.5	66.0	66.5
932	67	68.5	67.5	68.0	67.5	69.5	68.0	70.0
948	67	68.5	68.0	68.0	68.5	69.0	69.0	69.5
1001	68	66.0	67.5	69.0	70.5	67.5	70.5	67.0
1004	69	68.5	68.0	68.0	68.0	71.0	69.0	70.0
1034	70	68.5	68.0	70.0	69.0	73.0	72.0	72.0
1054	71	66.0	67.5	70.0	68.0	70.5	71.0	69.0
1109	72	66.0	68.0	70.0	67.5	71.0	72.0	70.0
1109	72	66.0	70.5	71.0	70.0	69.0	74.0	72.0
1121	71	66.1	68.5	70.0	68.0	71.5	72.0	71.0
1125	71	68.5	69.0	71.0	69.0	69.0	72.0	68.0
1207	74	66.5	69.0	74.0	68.0	76.0	75.0	75.0
1225	75	66.3	69.5	87.5	66.0	77.0	76.0	76.0

APPENDIX E

MULTIPLE REGRESSION OF FIELD SURVEY TEMPERATURE DATA

In the following tables, the variables are indentified as follows:

DA = Average dispensed fuel temperature

UF = Underground fuel temperature

AM = Ambient temperature

Table E-1

Statistics for Total Sample

PROBLEM CODE	REFFLD
NUMBER OF CASES	2637
NUMBER OF ORIGINAL VARIABLES	3
NUMBER OF VARIABLES ADDED	7
TOTAL NUMBER OF VARIABLES	10
NUMBER OF SUB-PROBLEMS	3
THE VARIABLE FORMAT IS	(37X,F3.1,21X,F3.1,1X,F3.0)

VARIABLE		MEAN	STANDARD DEVIATION
DA	1	69.72316	23.74181
UF	2	69.74094	23.12682
AM	3	64.22638	23.20882
A-U	4	-5.52289	9.26426

CORRELATION MATRIX

VARIABLE NUMBER	1	2	3	4
1	1.000	0.991	0.946	-0.105
2		1.000	0.920	-0.192
3			1.000	0.208
4				1.000

COVARIANCE MATRIX

VARIABLE NUMBER	1	2	3	4
1	563.674	544.017	521.045	-23.076
2		534.850	493.842	-41.097
3			538.649	44.725
4				85.826

Table E-2
Regression Data for Total Sample

(N = 2637)

STEP NUMBER 1
VARIABLE ENTERED 2

MULTIPLE R 0.9908
STD. ERROR OF EST. 3.2148

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	1	1458609.000	1458609.000	141133.938
RESIDUAL	2635	27232.527	10.335	

VARIABLES IN EQUATION

VARIABLE	COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT	-1.21315)		
UF 2	1.01714	0.00271	141133.9375 (2)

STEP NUMBER 2
VARIABLE ENTERED 3

MULTIPLE R 0.9946
STD. ERROR OF EST. 2.4674

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	2	1469805.000	734902.500	120709.875
RESIDUAL	2634	16036.242	6.088	

VARIABLES IN EQUATION

VARIABLE	COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT	-1.17523)		
UF 2	0.80785	0.00530	23195.3789 (2)
AM 3	0.22667	0.00529	1839.0271 (2)

Table E-3

Statistics for Moderate Temperature Sample

PROBLEM CODE	SPRING
NUMBER OF CASES	187
NUMBER OF ORIGINAL VARIABLES	3
NUMBER OF VARIABLES ADDED	1
TOTAL NUMBER OF VARIABLES	4
NUMBER OF SUB-PROBLEMS	2
THE VARIABLE FORMAT IS	(37X,F3.1,21X,F3.1,1X,F3.0)

VARIABLE		MEAN	STANDARD DEVIATION
DA	1	63.97861	3.61106
UF	2	66.95920	1.07839
AM	3	58.65775	8.60168
A-U	4	-8.30209	8.57029

CORRELATION MATRIX

VARIABLE NUMBER	1	2	3	4
1	1.000	0.123	0.842	0.830
2		1.000	0.092	-0.033
3			1.000	0.992
4				1.000

COVARIANCE MATRIX

VARIABLE NUMBER	1	2	3	4
1	13.040	0.478	26.148	25.671
2		1.163	0.853	-0.309
3			73.989	73.138
4				73.450

Table E-4

Regression Data for Moderate Temperature Sample (N = 187)

STEP NUMBER 1
VARIABLE ENTERED 3

MULTIPLE R 0.8418
STD. ERROR OF EST. 1.9543

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	1	1718.842	1718.842	450.051
RESIDUAL	185	706.554	3.819	

VARIABLES IN EQUATION

VARIABLE	COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT	43.24840)		
AM 3	0.35341	0.01666	450.0503 (2)

STEP NUMBER 2
VARIABLE ENTERED 2

MULTIPLE R 0.8431
STD. ERROR OF EST. 1.9526

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	2	1723.860	861.930	226.068
RESIDUAL	184	701.537	3.813	

VARIABLES IN EQUATION

VARIABLE	COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT	33.11020)		
UF 2	0.15295	0.13333	1.3160 (2)
AM 3	0.35165	0.01672	442.5522 (2)

Table E-5

Statistics for High Temperature Sample

PROBLEM CODE	SUMMER
NUMBER OF CASES	1790
NUMBER OF ORIGINAL VARIABLES	3
NUMBER OF VARIABLES ADDED	1
TOTAL NUMBER OF VARIABLES	4
NUMBER OF SUB-PROBLEMS	2
THE VARIABLE FORMAT IS	(37X,F3.1,21X,F3.1,1X,F3.0)

VARIABLE		MEAN	STANDARD DEVIATION
DA	1	84.88658	3.05835
UF	2	84.45976	1.20224
AM	3	78.04189	9.51606
A-U	4	-6.42408	9.15581

CORRELATION MATRIX

VARIABLE NUMBER	1	2	3	4
1	1.000	0.378	0.732	0.711
2		1.000	0.356	0.239
3			1.000	0.992
4				1.000

COVARIANCE MATRIX

VARIABLE NUMBER	1	2	3	4
1	9.354	1.391	21.307	19.913
2		1.445	4.075	2.629
3			90.555	86.469
4				83.829

Table E-6

Regression Data for High
Temperature Sample (N = 1790)

STEP NUMBER 1
VARIABLE ENTERED 3

MULTIPLE R 0.7321
STD. ERROR OF EST. 2.0838

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	1	8969.254	8969.254	2065.512
RESIDUAL	1788	7764.191	4.342	

VARIABLES IN EQUATION

VARIABLE	COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT	66.52361)		
AM 3	0.23530	0.00518	2065.5134 (2)

STEP NUMBER 2
VARIABLE ENTERED 2

MULTIPLE R 0.7428
STD. ERROR OF EST. 2.0486

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	2	9233.816	4616.908	1100.109
RESIDUAL	1787	7499.629	4.197	

VARIABLES IN EQUATION

VARIABLE	COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT	38.81367)		
UF 2	0.34232	0.04311	63.0399 (2)
AM 3	0.21989	0.00545	1629.6946 (2)

Table E-7

Statistics for Low Temperature Sample

PROBLEM CODE	WINTER
NUMBER OF CASES	660
NUMBER OF ORIGINAL VARIABLES	3
NUMBER OF VARIABLES ADDED	1
TOTAL NUMBER OF VARIABLES	4
NUMBER OF SUB-PROBLEMS	2
THE VARIABLE FORMAT IS	(37X,F3.1,21X,F3.1,1X,F3.0)

VARIABLE		MEAN	STANDARD DEVIATION
DA	1	30.22575	5.44865
UF	2	30.62665	3.58264
AM	3	28.33484	8.41652
A-U	4	-2.29237	8.95500

CORRELATION MATRIX

VARIABLE NUMBER	1	2	3	4
1	1.000	0.750	0.467	0.139
2		1.000	0.058	-0.346
3			1.000	0.917
4				1.000

COVARIANCE MATRIX

VARIABLE NUMBER	1	2	3	4
1	29.688	14.647	21.405	6.760
2		12.835	1.742	-11.093
3			70.838	69.098
4				80.192

Table E-8

Regression Data for Low
Temperature Sample (N = 660)

STEP NUMBER 1
VARIABLE ENTERED 2

MULTIPLE R 0.7503
STD. ERROR OF EST. 3.6046

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	1	11014.758	11014.758	847.736
RESIDUAL	658	8549.473	12.993	

VARIABLES IN EQUATION

VARIABLE	COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT	-4.72371)		
UF 2	1.14115	0.03919	847.7375 (2)

STEP NUMBER 2
VARIABLE ENTERED 3

MULTIPLE R 0.8619
STD. ERROR OF EST. 2.7670

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	2	14534.117	7267.059	949.175
RESIDUAL	657	5030.113	7.656	

VARIABLES IN EQUATION

VARIABLE	COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT	-11.37380)		
UF 2	1.10383	0.03014	1341.6296 (2)
AM 3	0.27503	0.01283	459.6748 (2)

APPENDIX F

COMPUTER PROGRAM LISTING

Table F-1 Computer Program Listing

```
1*    C      REFUELING LOSSES AREA MODEL,  MALCOLM SMITH, 4/15//4
2*    C
3*    C           REVISED BY W. F. BILLER  9/15/75
4*    C
5*          INTEGER OPT1, OPT2, OPT3
6*          DIMENSION R(16), REG(5), TEMP(3), PV(400), DF(400), AM(16,400),
7*         1ND(400), C(8), HCLOSS(16,400), TOTDAY(400), TOTHR(16), GDAY(400)
8*    C
9*    C  COEFFICIENTS OF BASE EQUATIONS ON NEXT SIX DATA CARDS
10*   C
11*         DATA REG/-9.1703E-2,1.1521E-3,-1.2605E-3,5.4094E-2,1.0725E-4/
12*         DATA TEMP/-1.17523, 0.80785, 0.22667/
13*         DATA R/.0175,.0435,.0445,.0585,.0605,.07,.0715,.0695,.0755,.077,.0
14*        1765,.0835,.0845,.0775,.055,.035/
15*         DATA DELT/ 7.0/
16*         DATA SPIL/ 0.3/
17*         ICRD=5
18*         IPRT=6
19*         E=2.718281828
20*   C
21*   C  NTIMES = NUMBER OF DATA SETS; E.G., IF ESTIMATING LOSSES FOR
22*   C  ONE SUMMER MONTH AND ONE WINTER MONTH, THEN NTIMES = 2
23*   C
24*   C      OPT1 = 0  WILL NOT PRINT LOSS EQUATION COEFFICIENTS
25*   C      OPT1 = 1  WILL PRINT LOSS EQUATION COEFFICIENTS
26*   C
27*         READ(ICRD, 1100) NTIMES, OPT1
28*    1100 FORMAT(3X, I2, 4X, I1)
29*   C
30*   C      COMPUTE COEFFICIENTS OF DISPLACED HC LOSS EQUATION
31*   C
32*         CALL COEF(TEMP, C, REG, DELT)
33*         IF(OPT1 .EQ. 0) GO TO 20
34*   C
35*   C      PRINT COEFFICIENTS IF OPT1 = 1
36*   C
37*         WRITE(IPRT, 1010)
```

Table F-1 continued

```
      1010 FORMAT('1', 5X, 'THE CALCULATED COEFFICIENTS ARE:'/)
           DO 60 I=1,8
        60 WRITE(IPRI,1015)I,C(I)
      1015 FORMAT(11X,'C(',I1,') = ',E15.5/)
        20 CONTINUE
           DO 999 IJ=1,NTIMES
           TOTAL=0.
           TOTGAL=0
C
C  NDAYS = NUMBER OF DAYS OVER WHICH LOSS IS TO BE ESTIMATED
C
C
C      OPT2 = 0  MEANS GALLONS PER DAY (GDAY), REID VAPOR PRESSURE (PV),
C                UNDERGROUND FUEL TEMPERATURE (UF), ARE CONSTANT OVER
C                NDAYS
C      OPT2 = 1  MEANS THEY ARE VARIABLE OVER NDAYS
C
C      OPT3 = 0  WILL NOT PRINT INPUT DATA
C      OPT3 = 1  WILL PRINT INPUT DATA
C
           READ(ICRD, 1000) NDAYS, OPT2, OPT3
      1000 FORMAT(2X, I5, 2(4X, I1))
           DO 10 I=1,NDAYS
        10 TOTDAY(I)=0.
           DO 15 I=1,16
        15 TOTHR(I)=0.
C
C  READ IN FOR EACH DAY (ONE CARD PER DAY): DAY, ND(J); GALLONS PER DAY,
C  GDAY(J); REID VAPOR PRESSURE, PV(J); UNDERGROUND FUEL TEMPERATURE IN
C  DEG F, UF(J).  IF PARAMETERS CONSTANT OVER NDAYS, USE ONE CARD
C
           IF(OPT2 .EQ. 0) GO TO 25
           DO 21 J = 1, NDAYS
           READ(ICRD, 1020) ND(J), GDAY(J), PV(J), UF(J)
        21 CONTINUE
      1020 FORMAT(I5, 5X, F10.0, 2(5X, F5.0))
C
C      TEST FOR CORRECT SEQUENCE OF INPUT CARDS
C
           DO 24 J = 1, NDAYS
           IF(ND(J) .NE. J) GO TO 27
        24 CONTINUE
```

Table F-1 Continued

```
80*           GO TO  35
81*        27 WRITE(IPRT, 6000) J, ND(J), GDAY(J), PV(J), UF(J)
82*      6000 FORMAT('1 GDAY,PV,UF INPUT CARDS NOT IN SEQUENCE'/
83*          1  I5, I5, F10.0, 2(5X, F5.0))
84*           STOP
85*        25 READ(ICRD, 1025) GDAYC,PVC,UFC
86*      1025 FORMAT(10X, F10.0, 2(5X, F5.0))
87*           DO 26 I =1, NDAYS
88*           GDAY(I) = GDAYC
89*           PV(I) = PVC
90*        26 UF(I) = UFC
91*     C
92*     C  READ IN FOR EACH HOUR OF EACH DAY THE AMBIENT TEMP. IN DEG F, AM(I,J)
93*     C
94*        35 READ(ICRD, 1030)(ND(J), (AM(I,J), I = 1, 16), J = 1, NDAYS)
95*      1030 FORMAT(I5, 1X, 16F4.0)
96*     C
97*     C      TEST FOR CORRECT SEQUENCE OF INPUT CARDS
98*     C
99*           DO 28 J = 1, NDAYS
100*          IF(ND(J) .NE. J) GO TO 29
101*       28 CONTINUE
102*          GO TO  36
103*       29 WRITE(IPRT, 6010) J, ND(J), AM(I,J)
104*     6010 FORMAT('1  AM(I,J) INPUT CARDS NOT IN SEQUENCE'/
105*         1 I3, I3, 16F4.0)
106*          STOP
107*     C
108*     C      PRINT INPUT DATA IF CALLED FOR BY OPTION 3 = 1
109*     C
110*        36 IF(OPT3 .EQ. 0) GO TO 45
111*           WRITE(IPRT,7000)
112*     7000 FORMAT('1',T40,5('* '),'INPUT DATA',5(' *')//'  DAY    FUEL      RVP
113*         1   UNDERG*D',13(' *'),' AMBIENT TEMPERATURE, DEG F ',13(' *')/T7,'
114*         2DISPENSED',T26,'FUEL'/T26,'TEMP.  0600 0700 0800 0900 1000 1100 12
115*         300 1300 1400 1500 1600 1700 1800 1900 2000 2100'/T34,16('TO    ')/T
116*         47,'(GAL/DAY) (PSIA) (DEG F)  0700 0800 0900 1000 1100 1200 1300 14
117*         500 1500 1600 1700 1800 1900 2000 2100 2200'//)
118*          WRITE(IPRT,7010)(J, GDAY(J), PV(J), UF(J), (AM(I,J), I = 1,16)
119*         1 , J = 1, NDAYS)
120*     7010 FORMAT(I5, 1PE10.3, 2X, 0PF4.1, 4X, F4.0, 2X, 16F5.0)
121*       45 CONTINUE
```

Table F-1 Continued

```
C
C  COMPUTE HYDROCARBON REFUELING LOSS FOR EACH HOUR OF EACH DAY
C
      DO 70 J = 1, NDAYS
      DO 65 I = 1, 16
   65 HCLOSS(I,J) = (SPIL + E**(C(1) + C(2)*PV(J) + C(3)*AM(I,J)+
     1 C(4)*DF(J) + C(5)*PV(J)*AM(I,J) + C(6)*PV(J)*DF(J) +
     2 C(7)*AM(I,J)*DF(J) + C(8)*AM(I,J)*AM(I,J)))
     3 *R(I)*GDAY(J)/453.6
   70 CONTINUE
C
C  COMPUTE DAILY LOSS TOTALS
C
      DO 80 I=1,NDAYS
      DO 80 J=1,16
   80 TOTDAY(I)=TOTDAY(I)+HCLOSS(J,I)
C
C  COMPUTE TOTAL LOSS OVER SPECIFIED PERIOD
C
      DO 90 I=1,NDAYS
   90 TOTAL=TOTAL+TOTDAY(I)
 1040 FORMAT(1H1/5X,'SUMMARY OF LOSSES BY DAY, IN POUNDS OF HYDROCARBONS
     1'/)
 1050 FORMAT(20X,'DAY ',I3,' LOSS =',F8.0)
      WRITE(IPRT,1040)
C
C  OUTPUT LOSS BY DAY IN POUNDS OF HYDROCARBONS
C
      DO 100 I=1,NDAYS
  100 WRITE(IPRT,1050)I,TOTDAY(I)
 1060 FORMAT(/5X,'THE TOTAL LOSS OVER THE ',I3,'-DAY PERIOD =',F8.0)
C
C  OUTPUT TOTAL LOSS OVER SPECIFIED PERIOD OF TIME
C
      WRITE(IPRT,1060)NDAYS,TOTAL
C
C  COMPUTE AVERAGE LOSS IN GRAMS/GALLON
C
      DO 105 I=1,NDAYS
  105 TOTGAL=TOTGAL+GDAY(I)
      AVGE=TOTAL/TOTGAL*453.6
 1065 FORMAT(/5X,'THE AVERAGE LOSS =',F5.2,' GMS/GAL')
```

Table F-1 Continued

```
164*    C
165*    C  OUTPUT OVERALL AVERAGE LOSS IN GRAMS PER GALLON
166*    C
167*          WRITE(IPRT,1065)AVGE
168*     1070 FORMAT(1H1/5X,'SUMMARY OF LOSSES BY HOUR, IN POUNDS OF HYDROCARBON
169*         1S'/)
170*          WRITE(IPRT,1070)
171*    C
172*    C  COMPUTE HOURLY LOSSES SUMMED OVER ALL DAYS
173*    C
174*          DO 110 I=1,16
175*          DO 110 J=1,NDAYS
176*      110 TOTHR(I)=TOTHR(I)+HCLOSS(I,J)
177*     1080 FORMAT(20X,'HOUR ',I2,' LOSS =',F8.0)
178*    C
179*    C  OUTPUT LOSS BY HOUR, SUMMED OVER ALL DAYS, IN POUNDS OF HYDROCARBONS
180*    C
181*          DO 120 I=1,16
182*      120 WRITE(IPRT,1080)I,TOTHR(I)
183*      999 CONTINUE
184*          STOP
185*          END
```

```
  1*          SUBROUTINE COEF(X, Y, REG, DELT)
  2*          DIMENSION X(3), Y(8), REG(5)
  3*          Y(1) = REG(1) + REG(3)*DELT + REG(5)*X(1)*DELT
  4*          Y(2) = REG(2)*X(1) + REG(4)
  5*          Y(3) = REG(3) + REG(5)*X(1) + REG(5)*X(3)*DELT
  6*          Y(4) = REG(5)*X(2)*DELT
  7*          Y(5) = REG(2)*X(3)
  8*          Y(6) = REG(2)*X(2)
  9*          Y(7) = REG(5)*X(2)
 10*          Y(8) = REG(5)*X(3)
 11*          RETURN
 12*          END
```